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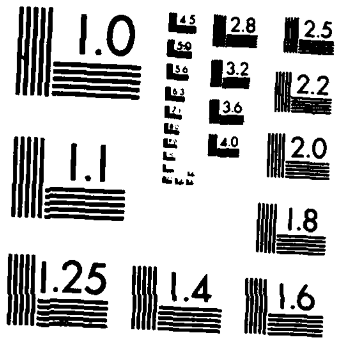
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THE FEASIBILITY OF A COST-EFFECTIVENESS ASSESSMENT OF WEAPON SYSTEM WARRANTIES: A CASE STUDY OF THE F-16 RELIABILITY IMPROVEMENT WARRANTY (RIW) PROGRAM

THESIS

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THESIS

Presented to the Faculty of the School of Systems and Logistics

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Abstract

As DOD's percentage of the budget continues to decline, there is an increasing need to get more for the defense dollar. Weapon system warranties which are now required by law are one way to achieve this objective. Congress has requested that only cost-effective warranties be procured. Consequently, DOD is requiring all services to conduct cost/benefit studies of warranties.

This thesis considered the information required to conduct such an analysis and investigated the availability of such information by looking at the F-16 Reliability Improvement Warranty contract (F33657-77-C-0062) as an example. A simple theoretical manufacturer's cost model of warranty relationships is used as a reference in identifying the overall structure and general types of information necessary for warranty cost/benefit analysis. Warranty experts from Aeronautical Systems Division (AFSC) were interviewed and asked about the availability of the information discussed by the model. The research concluded that critical information necessary to perform valid cost/benefit or effectiveness assessments of warranties is missing.

THE FEASIBILITY OF A COST-EFFECTIVENESS ASSESSMENT OF WEAPON SYSTEM WARRANTIES: A CASE STUDY OF THE F-16 RELIABILITY IMPROVEMENT WARRANTY (RIW) PROGRAM

I. Introduction

General Issue

Today's Defense environment combines spending priority conflicts with increasing cost for weapon systems, personnel, and operations. With emphasis in Congress on federal deficit reduction, the Department of Defense (DOD) is faced more than ever with the task of spending defense dollars wisely. Within this context, warranties have received increased consideration. Warranties, with their emphasis on reliability, encourage the production of more effective weapon systems which are cheaper to operate. However, since warranties cost money, it is necessary to evaluate the benefits and costs of any proposed warranty. This thesis investigates the availability of the necessary benefit and cost information by examining Air Force experience with the F-16 Reliability Improvement Warranty (RIW) program.

For over two decades, the DOD managed the acquisition of major weapon systems and many other notable projects using the techniques of a correction of deficiency clause (26:25). Although this technique is credited with allowing the development of complex weapon systems in minimum time and at minimum acquisition cost, products continue to be fielded that contain defects or that do not perform their intended

purpose. Therefore, this raises the issue of who is responsible for the correction of these deficiencies. As a result of these deficiencies, federal officials in both the legislative and executive branches are becoming increasingly concerned about the reliability/maintainability of new weapon systems. Specifically, some members of the legislative branch believe that requiring defense contractors to warrant that their equipment will work may resolve this concern (13). Consequently, Congress has passed recent legislatior requiring the DOD to obtain warranties for most weapon system procurements. They believe that the use of warranties will act as the tool necessary in motivating contractors to assure that the products delivered will work as advertized; thereby reducing life cycle costs by decreasing operation, maintenance, and support costs (42).

Congress has further directed that each component of the DOD conduct cost effectiveness analysis of proposed warranties prior to application of a warranty to a project. It is not the intent of the recently enacted warranty legislation to require a warranty on weapon system procurement should a warranty be determined not cost effective. However, to date both Congress and the General Accounting Office have been concerned about the application and utility of warranty analysis (12). The January 1986 task force report by the Air Force Product Performance Agreement Center (PPAC) supports this concern. It states that:

> Questions have been raised regarding the services' compliance with the need to determine cost effec-

> tiveness of warranties...a need exists to examine the Air Force approach to warranty implementation with particular emphasis on cost-benefit analysis and related concerns. [2:6]

Therefore, research in the area of identifying, measuring, and evaluating the benefits/costs of warranties will contribute to the DOD's ability to conduct effective analysis of warranty impact on weapon system procurement.

Present Problem

This section will highlight the most recent changes that apply to DOD warranty implementation and also the concerns about the benefit/cost analysis application.

Public Law Impact. During the last two years, two public laws (P.L. 98-212 and P.L. 98-525) have been passed that have a significant impact on the current acquisition regulation (the Federal Acquisition Regulation) for warranty application. The key changes are that these laws now require the inclusion of a warranty for most weapon systems and the latter law requires that prior to procurement warranties must be determined cost-effective through benefit-cost analysis. If a warranty is determined not to be cost-effective, Congress must be notified (30:46; 50:386).

The new warranty legislation referenced above does not intend that warranties be acquired which are not cost-effective. Consequently, failure by the DOD to conduct cost-benefit analysis prior to warranty implementation guarantees would defeat the intent of the congressional warranty requirements. Therefore, some form of cost-benefit analysis

is required to comply with legislative requirements. Provisions do exist in the new warranty legislation for waiver of the warranty requirement if the benefits to be received are not expected to be cost effective. According to the AF PPAC task force report, a DOD supplement to the Federal Acquisition Regulation (FAR) contains the following guidance for weapon system warranty implementation:

> It is DOD policy to only obtain warranties that are cost effective...In order to determine whether use of a warranty would be cost-effective, an analysis must be performed to compare the benefits to be derived from the warranty with its acquisition and administrative costs. The analysis should examine a weapon system's life cycle cost, both with and without a warranty. [2:6]

Cost-Benefit Analysis Concerns. The present problem facing the DOD is how to determine the cost-effectiveness of a warranty. While the new warranty legislation and the FAR contain the legislative and regulatory requirements, there seems to be no single directive that covers the policy and guidance required to effectively perform cost-benefit analysis for warranty implementation.

In a 1985 Air Force Institute of Technology thesis, Captain's Hernandez and Daney note that, despite the formal directives issued, there is little real guidance for field personnel on how to conduct cost-benefit analysis of warranties (30:63). In addition, the sharing of knowledge gained from implementing the new system level warranty law between organizations has been little or nonexistent. The benefits of experience do not seem to be passed on. Further, the thesis concludes that warranty implementation is only

superficially mentioned in any of the government classes on contract administration; and there is currently no dedicated system level warranty training classes for cost-benefit analysis, administration, or tracking of data nor does there appear to be plans to develop one (30:75-76). The problem faced by the DOD of how to determine the cost-effectiveness of a warranty is further supported by the research of Hernandez and Daney. They conclude that:

> USAF field personnel are for the most part unable to perform a cost-benefit analysis for a weapon system warranty...People did not know what type of approach/ structure to use for a warranty cost-benefit analysis. Instead, the USAF people we interviewed relied heavily on the contractor to price the warranty and then analyzed the contractor's methodology instead of preparing an independent estimate for comparison purposes. This is a potentially serious problem since the heart of determining warranty cost effectiveness and affordability should be the cost-benefit analysis, which from our research was not being accomplished independently. [30:63]

Definition and Types of Warranties

Definition. The term warranty as it is used today is understood generally to mean the expressed or implied obligations of the seller of property to his buyer. It applies to both real property transactions and to personal property transactions, but its most frequent use seems to be in connection with transactions involving the sale of goods. For the purpose of this research, a warranty is defined according to the Federal Acquisition Regulation (FAR); as "a promise or affirmation given by a contractor to the government regarding the nature, usefulness, or condition of the

supplies or performance of services furnished under the contract (6:2-1; 17:46-49).

In today's government contracts the words warranty and guaranty are often used interchangeably because of their common etymological origin. However, probably the better use is to define warranty as the obligation of a seller of goods with respect to their quality or certain other conditions of sale; and to define guaranty as the obligation undertaken by one party to stand secondarily responsible for the obligation of another party (52:24; 53).

Types. Although there exists many different kinds of warranties, these different kinds always fall under two specific types with regard to providing buyer protection - the implied warranty and the expressed warranty (4:10; 43:14). According to Dennis Allen in her thesis Application of Reliability Improvement Warranty (RIW) to DOD procurement, an implied warranty exists "in that the seller is providing merchantable goods which are to be used for a purpose known to both the buyer and seller" (4:10). To provide protection to buyers of goods and services, uniform legal provisions have been enacted in all the states. These provisions, known as the Uniform Commercial Code (UCC), are now recognized as the basis of transaction for any public or private contract. The UCC view on implied warranties is as follows:

> Where the seller at the time of contracting has reason to know any particular purpose for which the goods are required and that the buyer is relying on the seller's skill or judgement to select or furnish suitable goods, there is, unless excluded or modified under the contract's next section, an

> implied warranty that the goods shall be fit for such purpose. [5:86]

In other words, as stated by John Rannenberg in his thesis Warranties in Defense Acquisition: the Concept, the Context, and the Congress, "implied warranties are 'read into' contracts by common law, even if the specific language is not addressed (43:14). The second type of warranty, the expressed, is where "the seller warrants that the seller-designed systems, accessories, equipment, and parts shall be free from defects in design, material, and workmanship and shall conform to the detailed specification requirements over some specified period of time" (43:15). It becomes part of the bargain. In general, warranties, whether implied or expressed, are constructed as consistent with each other and as cumulative unless such construction is unreasonable, in which case the intention of the parties shall determine which warranty dominates.

The new system level warranty law, P.L. 98-525, now requires that the DOD obtain three kinds of expressed warranties in contracts awarded for the production of weapon systems. These three kinds of warranties are described as follows in the AF PPAC task force report:

1. Design and Manufacturing warranty "requires that the item provided under the contract will conform to the design and manufacturing requirements specifically delineated in the production contract" (2:6).

2. Material and Workmanship warranty "requires that the item provided under the contract, at the time it is de-

livered, will be free from all defects in materials and workmanship (2:6).

3. Essential Performance Requirements warranty "requires that the item furnished under the contract will conform to the essential performance requirements of the item as specifically delineated in the production contract (2:6).

Past History

Former Deputy Under Secretary of Defense for Acquisition Management Mary Ann Gilleece states that "the DOD has had a long history in the use of warranties" (26:25). For many years, the services used varying approaches to warranties and correction of deficiencies. Initially, the Uniform Sales Act of 1906 was recognized as the basis for transacting any public or private contract (4:9). This Act served as the basic DOD procurement policy guide for many years, but it was replaced by the Uniform Commercial Code (UCC) in the early 1960s. Since at that time there were no federal laws conflicting with the UCC, the DOD was free to adopt these codes as the guide for government contracts (4:9). The evolution of laws and practices pertaining to the use of major weapon system warranties in DOD contracts centers on three sets of regulations and two public laws - the Armed Services Procurement Regulation (ASPR), the Defense Acquisition Regulation (DAR), the Federal Acquisition Regulation (FAR), P.L. 98-212, and P.L. 98-525.

ASPR. In 1964, the DOD issued its first set of detailed written instructions for the use of warranties in firm-fixed-

price contracts by means of the ASPR. Consequently, this regulation became the DOD's "basic statement of procurement policy for all military departments" (37:66). Warranties under the ASPR are distinguished from warranties in the commercial sector in that, except for construction warranties, they are usually expressed. No implied warranties are usually attached to government procured items. Further, the ASPR states, "when expressed warranties are included in contracts (except contracts for commercial items) all implied warranties of merchantability and fitness for a particular purpose shall be negated..." (18:1-324.4a). In addition, the Standard Inspection Clause says, "except as otherwise provided in a contract acceptance shall be conclusive except as regard to latent defects, fraud, or such gross mistakes as amount to fraud" (18:7-103.5). In other words, the inspection clause can invalidate any implied warranty even though it is not expressly negated. The ASPR considered the following kinds of expressed warranties: warranty of supplies for complex and non-complex items, correction of deficiencies, and warranty of services (18:144-150).

DAR. For many years the ASPR served as the basic DOD procurement policy guide, but it was eventually replaced by the DAR in the 1970s. However the ASPR clauses and provisions carried over to the DAR. Similar to the ASPR, the DAR furnished "uniform policies for the Departments of the Army, Navy, and Air Force relating to the procurement of supplies and services under the authority of Title 10, United

States Code, chapter 137" (37:66). Citing an Air Command and Staff College research report on Air Force Management of Warranties, Captains Hernandez and Daney state that the following are the five kinds of expressed warranties available for procurement application under both the ASPR and DAR:

> 1. Reliability Improvement warranty (RIW) is the latest type to be implemented in the DOD. An RIW is defined as a provision in either a fixed-price equipment overhaul contract in which for a fixed additional price: [30:25]
>
> The contractor agrees for a specified or measured period of use he will repair or replace (within a specified turnaround time) all equipment that fails (subject to specified exclusions if applicable); and [30:25]
>
> The contractor is provided with the monetary incentive, throughout the period of the warranty, to enhance the production design and engineering of the equipment so as to improve the field/operational reliability and maintainability of the system/equipment, thus reducing the required number of repairs. [30:25]
>
> 2. Correction of Deficiency Clause - Under this type of warranty, the contractor agrees to correct any design, material, or workmanship deficiencies which result in the specific item performing below specification and contractual requirements. Such clauses in Air Force Systems Command weapon system and government furnished aerospace equipment contracts usually apply to spare parts, aerospace ground equipment, and any other supplies included in the contract. [30:25]
>
> 3. Supply Warranty - Under this warranty, the contractor is responsible to replace or rework contract items if defects or nonconformance in design, material or workmanship are found prior to the expiration of the specified period of time or before occurrence of a specified event. [30:25-26]
>
> 4. Service Warranty - Under such a warranty, the contractor agrees to correct defective services providing defects of nonconformance in design and workmanship are found prior to the expiration of a specified period of time or before the occurrence of a specific event. [30:26]

> 5. Commercial Warranty - These are similar to supply and services warranties except the contractor determines responsibility. [30:26]

<u>FAR</u>. In April of 1984, the federal government published consolidated and simplified warranty policy guidance into one document - the Federal Acquisition Regulation (FAR). <u>Contract Management Magazine</u> states that the purpose of the FAR is to act as:

> one, government wide acquisition regulation that contains acquisition policies, procedures, contract clauses, and forms relating to all federal government agencies. It is neither a new set of regulations, nor is it more regulations. Rather, it is a consolidation and simplification of the regulations of the DAR, the National Aeronautical and Space Administration (NASA) Procurement Regulation, and the General Services Administration (GSA) Federal Procurement Regulation. [22:4]

According to the FAR, expressed warranties should provide for the following general items:

> 1. A contractual right for the correction of defects notwithstanding any other requirement of the contract pertaining to acceptance of the supplies or services by the government; and
>
> 2. A stated period of time or use, or the occurrence of a specified event, after acceptance by the government to assert a contractual right for the correction of defects. [17:46-49]

The key features of the FAR are that warranty use is not mandatory and its emphasis on warranties for component level material or workmanship.

<u>Public Law 98-212</u>. The most significant changes in recent years to DOD warranty policy are found in fiscal years 1984 and 1985 (31; 32). According to several articles, in late 1983 Congress included language in the 1984 DOD Appro-

priations Act to require the purchase of a warranty on all contracts for weapon systems (or their significant components), with one exception: when the DOD approves a waiver and notifies the Armed Services and Appropriation Committees in writing of the intent to waive warranty requirements (19:6; 21:24; 31:5-6). The enactment of this new law was in part due to public reaction to quality problems within the DOD acquisition process (28:11). The 1984 law addresses two distinct type of contract warranties, which are listed below:

> 1. The warranty that a weapon system and each significant component thereof be designed and manufactured so as to conform to the government's specification performance requirements, and
>
> 2. The warranty that, at the time of delivery to the government, the weapon system and each significant component thereof are free from such defects in materials and workmanship as would cause the system or component to fail to conform to the government's specified performance requirements [31:6].

The first type of warranty described above can be broken into two types as follows:

> 1. If a performance requirement is a test or demonstration, a guarantee clause will provide that upon failure to pass the test or demonstration, the contractor at its own expense will promptly perform all design and manufacture work needed to make the item conform to the requirement. [31:6]
>
> 2. If a performance requirement call for operation of the system for a specified time period without designated failures, and the system does not so perform, the contractor's obligation is the same as in 1. above. [31:6]

In their thesis Captains Hernandez and Daney state that "the key features of P.L. 98-212 are its emphasis on warranting the entire weapon system, its emphasis on having the

prime contractor correct defects, and its specific emphasis on warranting performance (30:42). The law asserts that a contractor is required to guarantee that it will bear the cost of all work and prompt repair or replacement of parts as necessary to achieve specified performance requirements. If the contractor fails to promptly repair or replace parts, it will be obligated to reimburse the government for the costs incurred in procuring parts from another source and in making or procuring the necessary repairs (51).

Public Law 98-525. As discussed above, P.L. 98-212 requires warranties on all weapon systems. The law was approved for a one-year period, as a trial measure, and became effective on 1 March 1984 (19:6). The literature reviewed indicates that this legislation generated much criticism from the military and defense contractors (13; 19:6; 21:24; 45). These articles further indicate that great pressure was exerted on Congress to water down the bill in the event of its being made permanent. The lawmakers did comply. Last year Congress passed Section 2403 of the fiscal year 1985 Authorizations Act (P.L. 98-525), which took effect on 1 January 1985 (39:34). Captains Hernandez and Daney conclude in their research that "there appears to be little difference between P.L. 98-212 and P.L. 98-525 except that the latter is more specific as to when the systems level warranty applies and when Congress is to be notified of waivers" (30:45).

The new public law incorporates six major changes to the warranty language contained in P.L. 98-212. They are summarized below:

1. The definition of "weapon system" and "component" were changed. A component is defined as any constituent element of a weapon system. A weapon system is defined as equipment that can be used directly by armed forces to carry out combat missions and that cost more than $100,000 or for which the eventual total procurement cost is more than 10 million.

2. The Secretary of Defense or his delegate can choose between the stated remedies for breach of warranty unless otherwise provided in the contract.

3. Language was added that clearly authorizes the negotiation of special details of a warranty, including reasonable exclusions, limitations, and duration.

4. The Secretary is empowered to reduce the price of any contract to collect the reasonable costs of corrective action undertaken by the U.S.

5. The warranty requirement applies to systems that are in mature, full-scale production. This means the manufacture of all units of a weapon system after the manufacture of the first one-tenth of the eventual total production, or the initial production quantity of such system, whichever is less.

6. The warranty also applies to any design or manufacturing requirement included in the contract amendment. [32:13; 45:34]

The previous paragraphs have only briefly covered some of the major changes to DOD warranty policy enacted by the ASPR, DAR, FAR, and P.L.'s 98-212/98-525. For a more complete description of the changes, one should consult the ASPR, DAR, FAR, and sections 794/2403 of P.L.'s 98-212/98525.

The use of warranties in government contracts and the administration of warranties continue to be a hot topics in

Congress. What the future holds for warranties in the DOD is best summarized by former Deputy Under Secretary of Defense Gilleece. "We're still in the gray areas in terms of dealing with this. It's been very difficult and will continue to be until we're in a position where we have some experience" (19:7).

Present Approaches of Evaluation

A cost-benefit analysis of warranties involves the comparison of benefits and costs for one particular warranty approach with the objectives of making the best choice from a number of warranty alternatives. Considering the above comment, the cost-benefit analysis of warranties is similar to that of any other type of economic analysis. AFP 178-8 describes economic analysis as:

> A framework for the orderly investigation of problems of choice; that ensures alternative ways of satisfying an objective are identified and investigates the costs and benefits of each of these alternatives. This organized and complete presentation of alternatives allows the decision-maker to select the most cost-effective option available. [15:1-1]

Estimating Costs. According to several reports, there are at least three methods of estimating warranty costs (2:39; 49:4-2). These three methods include - the rule of thumb, the cost-estimating relationship (CER), and the bottom-up accounting method.

The rule of thumb method involves developing a ratio of one cost element to another. For example, in using this method for estimating warranty costs, one would develop a

ratio by dividing warranty cost by hardware cost and then express the warranty coat as a percentage of the baseline cost. When possible this percentage should be supported by historical data. There are advantages for using the rule of thumb method. It can provide a quick order of magnitude estimate while requiring a minimal amount of data. However, there exists disadvantages to using this method. First, while its simplicity is an advantage, it also is a disadvantage in that it gives only rough order magnitude, imprecise estimates. Lastly, its oversimplification may obscure relevant details that need to be considered.

A second method for estimating warranty costs, the CER, uses statistically developed parametric relationships for individual warranty elements. Several advantages to the CER method exist. First, once developed it is easy to use and can be revised as required. Second, more detail is provided than with the rule of thumb. Third, it is identifiable to and based on measured costs and therefore can be used to identify key cost drivers. Lastly, the estimate can provide a firm statistical basis for projection and predictions into the future. On the other hand, there are disadvantages to using this approach. First, an extensive data base is required. Second, a CER is costly due to the extensive development efforts evolved. Third, CERs require updating to make required changes necessitated by time. Finally, a CER is only as good as its similarity to the past. Also, if we

paid too much in the past it will cause us to pay too much in the future.

The last method for estimating warranty costs, the bottom-up accounting method, identifies all warranty cost elements required to estimate costs or factors and summarizes them into a total cost. This method requires a "build up" of costs from the contractor's accounting system and sometimes its elements may include costs based on the rule of thumb or CER methods. There are also distinct advantages for using this method. First, this approach is the most accurate for a particular warranty since it relies on a specific contractor's data. Second, it provides traceable and verifiable accountability. Finally, it can accommodate all warranty provisions. Conversely, there can be disadvantages to this approach. First, this method is usually expensive to develop. Second, it is a complicated method to understand and to use since it varies from contractor to contractor. Third, this approach takes more time to develop a usable estimate than the other two approaches. Finally, accurate, complete, and current data are needed to develop the estimate.

In summary, the methods available for estimating warranty costs are not really any different than those used for estimating other type of costs. However, the real difference in the warranty area is that there is a great deal of emphasis being placed on estimating costs in this area at

this time but the data base required for this is seriously lacking.

Estimating Benefits. For DOD to estimate the benefits that will result from a warranty they must first be identified and defined. Benefits may be either quantitative or qualitative. The quantitative benefits are normally stated in terms of controlling or improving equipment quality, availability, reliability, or supportability. These improvements can be quantified through the use of reliability and maintainability parameters such as Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR). On the other hand, qualitative benefits are not measurable in quantitative terms, but instead are based on subjective assessments and are normally stated in terms of risks assumed by the contracts or the quality of products delivered. Qualitative warranty benefits may include motivation for (6:7-12):

1. Emphasizing contractor design of the system to meet requirements at initial production release and to operate as intended in the field;

2. Resolving problem areas early and rapidly due to high visibility and management attention;

3. Providing more realistic estimates of field performance which permit improved accuracy for planning operations and support resources; and

4. Providing the incentive for the contractor to introduce no-cost engineering change proposals during the warranty period.

In any event, the benefits of warranties are the value of the output produced in an operational context. Consequently, the first step for DOD is to measure the change in reliability from warranty coverage.

Plan of this Thesis

The objective of this research is to determine the nature and availability of the data upon which to make a meaningful evaluation of the costs and benefits of weapon system warranties. In order to limit the scope of the research, only the nine warranted First Line Units (FLUs) of the F-16 program are considered.

In chapter two a theoretical model of warranty relationships, developed by Dr. Leroy Gill of the Air Force Institute of Technology, is used as a reference in identifying the overall structure and general types of information necessary to such an analysis. Chapter three presents an overview of the defense systems acquisition process and also discusses the warranty planning which should be accomplished during the process. Also included in chapter three is an overview of the history of the F-16 Reliability Improvement Warranty (RIW) and the management structure of the program. Additionally the equipment that was warranted on the F-16 program is identified. Chapter four assesses the feasibility of obtaining the information required to evaluate the costs and benefits of weapon system warranties. Also, the nature and availability of the information along with the problems involved in measuring the cost and benefits of weapon system warranties are discussed using the F-16 RIW as the case example. Finally, chapter five provides a conclusion and recommendations for future research.

II. Theoretical Considerations

The previous chapter gave an introduction to the background of the DOD acquisition community regarding system level warranties; including the types and kinds of warranties that exist, the evolution of warranty use in the DOD, and the current approaches used to evaluate warranties. This chapter discusses the economic analysis process of how to evaluate the benefits of product warranties and how to compare these benefits to their cost. To provide the reader an understanding of this issue the use of a simple manufacturer's cost model utilizing warranty claim costs and manufacturing costs, developed by Dr. Leroy Gill Associate Professor of Economics at the Air Force Institute of Technology (AFIT), will be used.

Defining the Nature of Benefits and Costs

An economic analysis is a systematic approach to complex problems of choice. In order to make the best possible choice it is necessary to evaluate the costs and benefits. If the DOD chooses to use some of its resources to purchase a warranty for a weapon system or for a particular component, then those resources will not be available for some other alternative use. Estimating the cost of such a choice is an estimate of the benefits that could otherwise have been obtained. Consequently, "Costs are the value of benefits lost" (20:62). Further, "getting the greatest benefit for a

given cost and minimizing cost for a given level of achievement are converse sides of a coin" (20:62).

Commercial Versus DOD Warranties

Taking into account that "DOD warranties are often compared to commercial warranties, a starting point for analysis is to ask why warranties are offered in the marketplace" (25:1). The micro-economic theory of supply and demand in a competitive market can be used to explain the existence and coverage levels of warranties. Further, research has shown that many consumers draw inferences about a product from its warranty (41; 47). Consumers believe that a product with a superior warranty will be associated with greater quality and less risk (47:38). Consequently, "one would expect that better warranties are produced up to the point where the increase in revenue associated with an improved warranty is just equal to the cost of that improvement" to the manufacturer (25:1). Looking at the nature of consumer demand, commercial warranties exist in response to two different interests of the consumer. "First, they offer a consumer 'insurance' that he will not have to pay the cost of a failure for a given period of time. Second, they offer 'assurance' that the product is truly equal to its advertised quality" (25:1).

Warranty as Insurance. As the above discussion indicates, the "insurance" aspect of a warranty provides the consumer protection in that the manufacturer promises to provide compensation against loss. To evaluate the insurance

aspects of warranties one can draw a generalization to a consumer's decision to purchase any type of insurance. A risk adverse individual should therefore be willing to pay more for an insurance policy than the expected value of their loss. Gill provides the following example of this concept in his unpublished working paper on Evaluating the Benefits and Costs of DOD Warranties:

> If the annual probability of an individual's house burning down is 1 in 100,000 and the house is worth $100,000, then the annual expected value of his loss is only $1. In other words, if the individual lived forever the average annual loss from fire would be $1. However, since in reality, the individual could lose $100,000 and be financially devastated, he may be willing to pay a premium of more than $1 in order to be protected from that risk. From the standpoint of a fire insurance company which ensures a million houses, the chance that all of the houses they insure will burn down is not 1 out of 100,000 but (1/100,000) to the 1,000,000 power, assuming that houses burning are independent events. [25:2]

From the above example, it is easy to see why a separate centralization of risks will significantly reduce the probability of a disastrous event. For this reason, the use of self insurance is popular for large scale activities that have small levels of variability of loss from year to year. This has been the case in the DOD for weapon system procurement until recent years.

Warranty as Assurance. "The 'assurance' aspect of warranties relies on the implicit assumption that the penalties associated with failures of the product are sufficient to induce a manufacturer to produce a product which is at least on average equal to its advertised level of quality (25:2).

In other words, a warranty can be an accurate signal of product reliability since a manufacturer offering a better warranty has an economic incentive to reduce the extent of warranty claims, and claims are reduced by making a more reliable product. If a manufacturer doesn't reduce warranty claims by building a better product, he will be faced with reduced profits or could even lose money. According to Gill, "this type of assurance is particularly valued for complex products which have numerous quality dimensions (25:3). Nonetheless, one must realize that the costs associated with paying warranty claims can be compared to the lesser costs of manufacturing a lower quality product. For example, suppose that a weapon system begins to have a particular type of failure. The contractor recognizes that the failure will recur and projects $500K worth of failures within the period of the warranty coverage. The contractor has the choice of either spending the $500K or building a more reliable product. If the cost of building a more reliable product were say $1 million, it would be in the best business interests of the contractor to pay the $500K in warranty claims than to build the more reliable product. Although the impression is given that better warranties result in more reliable products, the following model will confirm this intuition.

Impact of Warranties on Manufacturer Incentives

Under free market conditions the standard assumption is that the manufacturer is a profit maximizer. This means he

desires to realize the greatest possible difference between total revenue and total cost. Presumably, the level of product reliability produced is the profit maximizing one given demand and cost considerations. These same forces will determine whether a warranty is offered and the extent of its coverage. On the other hand, consider the case of a negotiated warranty such as DOD procures. Under this situation, the manufacturer's total revenue is assumed to be negotiated with DOD. "These negotiations typically specify the quantity to be purchased, the price per unit, the amount of various fixed payments, and the level of coverage" (25:3). The price DOD pays for warranty coverage can be explicitly addressed or it may be implicit to the per unit purchase price. Decreases in the level reliability of the product result in an increase in the number of warranty claims which in turn affects the manufacturer's profit (25:3). Alternatively, increases in the reliability of the product result in increased manufacturing cost which also affects a manufacturer's profit (34:24). Consequently, in a negotiated DOD contract a manufacturer will seek to minimize total cost in order to maximize his level of profit. To illustrate the effect of a warranty on a manufacturer's total cost, Figure 1 provides Gill's model of a manufacturer's total cost curve (25:5).

Figure 1 depicts (for a fixed number of units produced, Q*) "the standard case for a manufacturer's total cost when warranty claim costs are included" (25:7). The convex shape of the total cost curve in Figure 1 results from the assump-

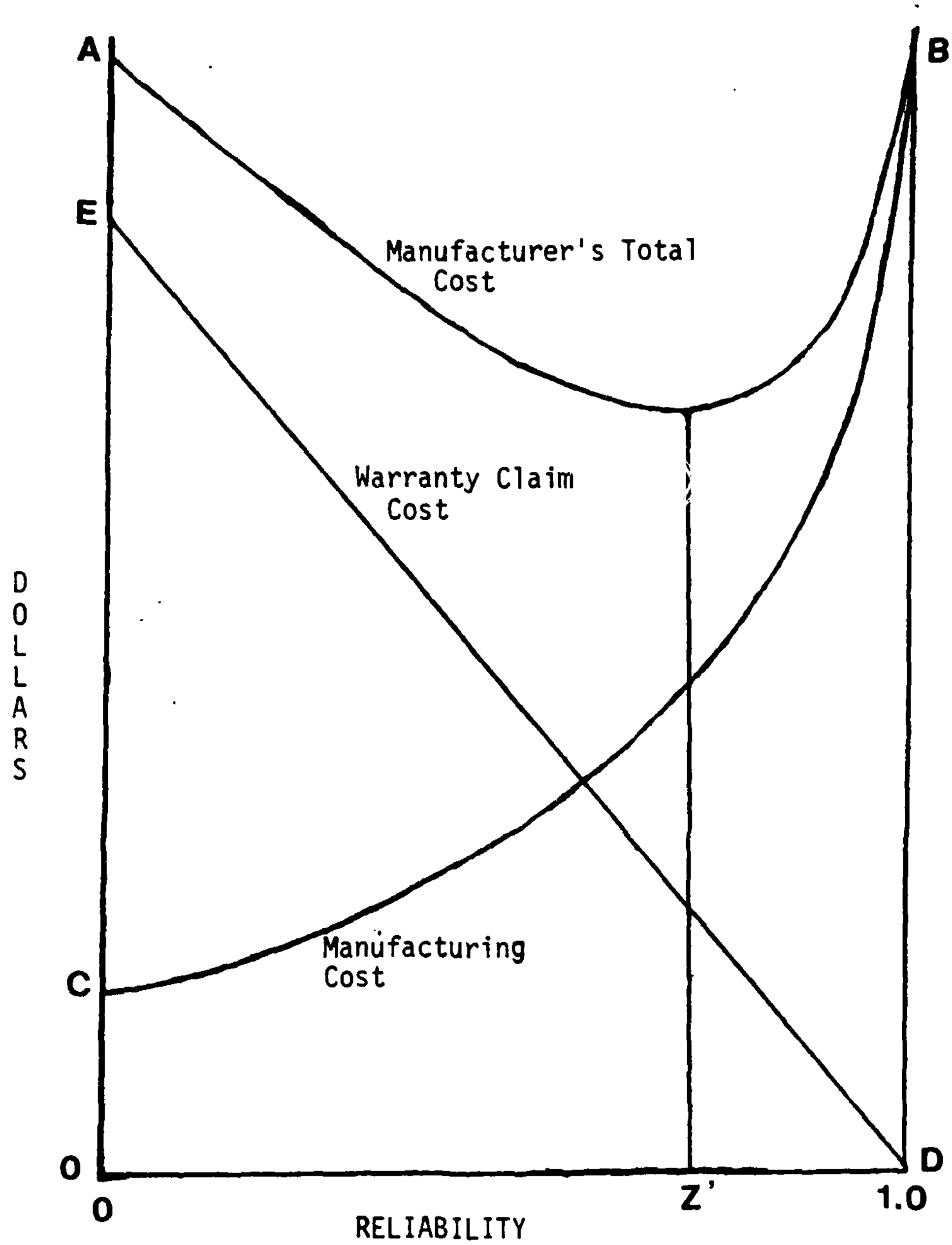


Figure 1. Derivation of the Manufacturer's Total Cost Curve (25:5)

tion that improvements in reliability cause manufacturing costs to increase at an increasing rate (25:7). A further assumption is that the warranty requires the manufacturer to pay a fixed penalty per failure (h) and each unit is operated for a fixed number of hours and discarded (25:3-4). Therefore, the manufacturer's total cost curve can be "obtained by vertically adding the warranty claim cost curve and the manufacturing cost curve" (25:4).

The warranty claim cost curve is a straight line and is equal to the fixed penalty cost per failure (h) times the number of failures (Q*). To illustrate this concept, suppose all the products the manufacturer produced fail (h=0), then the manufacturer's warranty claim costs would be equal the quantity of claims times the fixed penalty per failure (point E). Alternatively, if no products were to fail (h=1), then warranty claim costs would be equal to zero (D).

As illustrated by Figure 1, the manufacturing cost curve is the function of the quantity (Q*) of products produced and the reliability (Z) of those products (25:4). Since in Figure 1 the quantity of units produced (Q*) is fixed, the change in the level of manufacturing cost will depend on the cost of producing products of greater reliability (Z). For example, if reliability is equal to zero, then manufacturing costs would be equal to the value at point C. Conversely, if the products were 100 percent reliable, the manufacturing costs would be equal to the value at point B.

With total revenue assumed fixed, profit maximization in this situation will correspond to minimizing costs. Therefore, in relation to Figure 1, a manufacturer will try to obtain costs which correspond to the minimum point on the total cost curve which is depicted as the reliability of Z' (25:6).

To evaluate the effect of an increase in warranty coverage let us refer to Figure 2. If the DOD increases warranty coverage on a contract then the cost of failures will be more expensive to the manufacturer. This in turn will increase the manufacturer's fixed penalty per failure (h'). The associated shift in slope of the warranty claim cost curve, will change the manufacturer's total cost curve while the manufacturing cost curve remains unaffected (25:9). This can be explained by again noting that the total cost curve is equal to the vertical sum of the warranty claim cost curve and the manufacturing cost curve. Consequently, the minimum point on the total cost curve shifts to the right with the new reliability now equal to Z''. This can also be derived mathematically (25:4,6-7). As can be seen by the above example, increases in warranty claim penalties (h') motivate a manufacturer to produce units of higher reliability (25:7). However, "in reality, profit maximizing solutions may be bounded so that Z cannot fall below a given positive level due to political or market considerations" or the "maximum level of Z may be less than one due to technological constraints" (25:7).

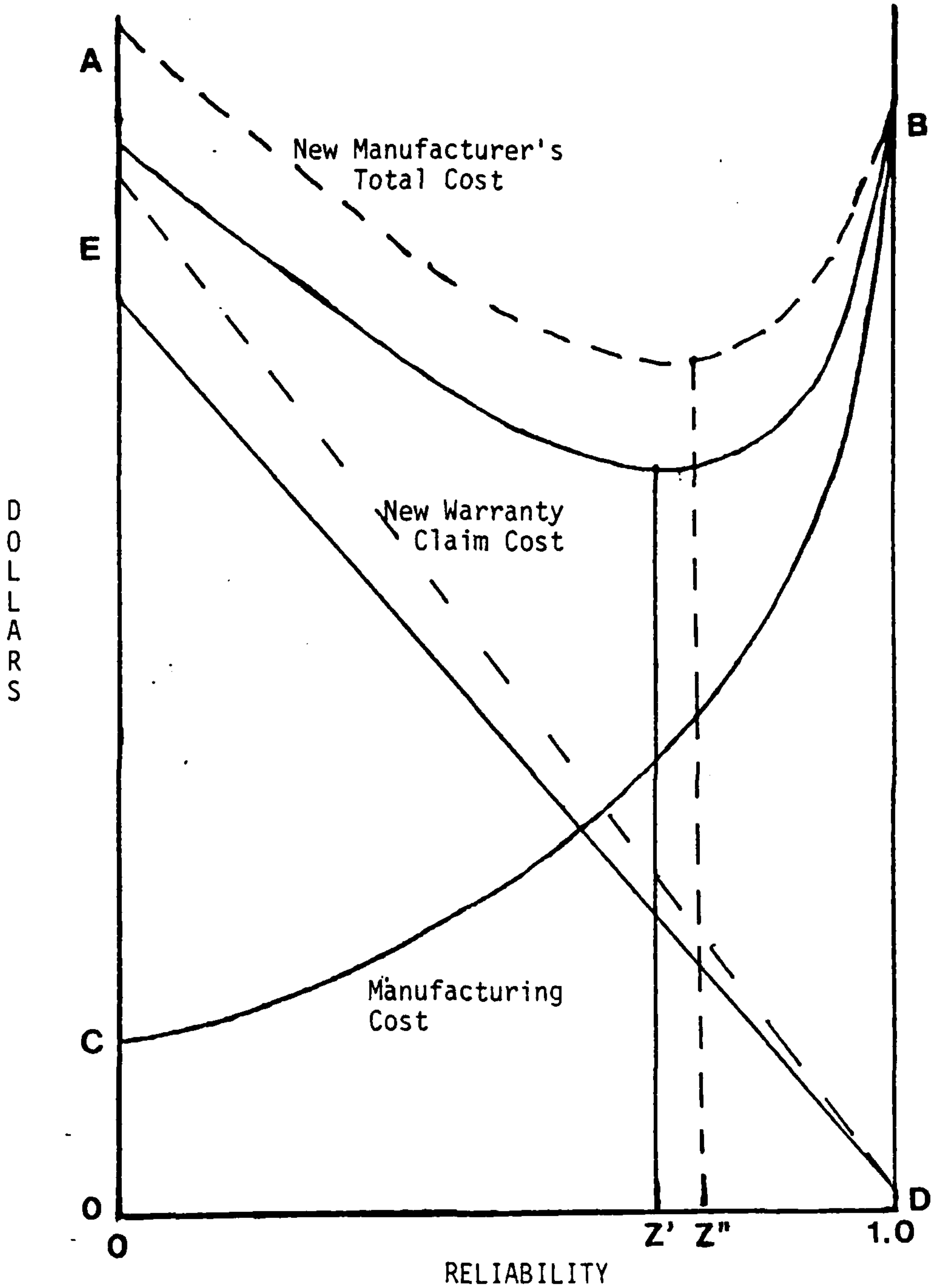


Figure 2. Affect on the Manufacturer's Total Cost Curve to an Increase in Warranty Coverage

The analysis of the models in Figures 1 and 2, suggests that increases in the level of warranty coverage affects a manufacturer's total cost and motivates them to produce more reliable products. Within these models, warranties affect a manufacturer's total cost through their impact on warranty claim costs and manufacturing costs (25:12). A manufacturer can minimize his total costs "when the incremental reduction in warranty claim costs is just offset by the increase in manufacturing costs associated with building a more reliable product" (25:12). Finally, the DOD can encourage a manufacturer to build a more reliable product by increasing the penalty per failure in the warranty coverage.

Defining the Benefits and Costs of DOD Warranties

In analysis it is necessary to accurately separate benefits from costs using a consistent rule. The recognized approach is to define benefits as the resulting operational improvement which DOD is spending money to obtain - ie. increased reliability. Costs are the resources DOD must use to obtain these improvements. The following considerations should be made when defining the benefits and costs of DOD warranties.

Benefits of Warranties. "The benefits of DOD warranties are the operational improvements realized by having available for use more reliable equipment" (25:7). Some negative aspects relating to the benefit of warranties are the longer repair time sometimes associated with contractor repair/ replacement action and the limitations on product use

sometimes imposed to preserve warranty coverage. Increased benefits are not cost savings. Consequently, when comparing alternatives it is required to separate cost from benefits. Since the DOD provides the service of national defense to its citizens, "the benefits of its expenditures are the value of the services produced" (25:8). Therefore, it follows that the benefits of a warranty in the DOD "are the value of the increased services which could result from the presence of a warranty in contrast to a specified prior situation" (25:8). A warranty could also bring about reductions in other types of cost, for instance fewer plane crashes due to more reliable components. Gill states that "this advantage is fully measured when comparing the total costs of different alternatives" (25:8). The benefits of these better aircraft components will relate to better mission performance instead of cost avoidance. As for the insurance aspects of warranties previously discussed, the same conclusion can be deduced since replacement costs for warranted systems are reduced or eliminated in contrast to the costs of operating non-warranted systems. As a result, the most important question that needs to be answered in terms of warranty benefits is the extent of the increase in reliability (Z) the DOD receives from an increase in different levels of warranty coverage.

Costs of Warranties. The costs of warranties are divided into two types - explicit and implicit costs. First, the explicit cost of DOD warranties can be defined as the sum of the manufacturer's total cost at a set level of relia-

bility and the manufacturer's profit. If the average profit of DOD manufacturer's is above the minimum level they require it might be possible to obtain improved warranty coverage at no additional cost to the DOD. The cost of the increased warranty coverage could be borne by the manufacturer in reduced profits. Who pays the additional costs for increased warranty coverage will depend on the bargaining power of the DOD versus that of the manufacturer.

In any event, the DOD should not pay more for increased reliability than the value of that benefit. If the DOD can estimate the change in total costs to the manufacturer at a higher level of h, this value "is likely to represent the manufacturer's minimally acceptable price for expanded warranty coverage on subsequent products since any lesser price would reduce his profits from previous levels" (25:10). The salient point is that in order to bargain intelligently, the DOD must estimate the increase in product reliability and the impact on the manufacturer's total cost.

To estimate the cost of a warranty or a warranty improvement to the manufacturer, the following information is needed:

1. the impact of reliability on the manufacturing cost of the product - M(Q,Z)
2. initial level of reliability - Z'
3. change in reliability - Z''
4. penalty cost per failure - h

The penalty cost per failure and the change in reliability estimates require knowledge of the number of failures before and after the warranty plus an estimate of the manufacturer's

cost to correct the situation according with the warranty contract provisions. Estimates of the manufacturing cost require detailed engineering and financial information regarding the production process.

The second type cost of DOD warranties, the implicit, refers to the administrative costs needed to enforce legal warranty claims. For example, if warranty claims are not filed or paid because of inadequate DOD documentation, the actual warranty claim cost curve for the manufacturer will differ from that implied by the warranty contract. Consequently, if adequate documentation is not being gathered by the DOD to enforce its warranty claims then the full value of the warranty may not be realized with regard to motivating the contractor. The result of not identifying and controlling implicit costs of DOD warranties could be less reliable products. In contrast to the above, favorable cost impacts of a warranty result from reduced operation and maintenance costs due to fewer failures and contractor absorbtion of at least some of the cost of fixing failures.

Implications with Regard to the Evaluation of DOD Warranties

Theoretically, the preceding discussion brings out important points with regard to the evaluation of the benefits and costs of a DOD warranty. First, for benefits, warranties increase product reliability. In order to evaluate this benefit, "one has to know or estimate the change in reliability which results from a warranty and the value of that change in reliability in an operational context

to DOD" (25:12). Second, for costs, "warranties increase the manufacturer's total cost" (25:12). In order for DOD to evaluate warranty costs one needs to know as much as possible about (1) "the actual cost to the manufacturer of a failure," (2) "the number of failures which occur at a given level of warranty coverage," and (3) "the manufacturing cost of building reliability into products" (25:13). It should be noted here, the actual cost to the manufacturer "could differ from the implied contractual cost because of a lack of adequate documentation or violation of warranty provisions" (25:13). Actual cost for a failure could also be decreased by the contractor making slow or incorrect repairs and by requiring extensive documentation.

For the purpose of evaluating the cost effectiveness of DOD warranties, the benefits and costs of warranties must be compared to those of other alternatives. These options include better reliability through better maintenance, greater purchases of less reliable/less expensive products or no change at all. To conclude, the benefits of warranties to DOD are the improved reliability they inspire from the contractor (25:13). The costs include not only the payments to the contractor but, in addition, the costs to DOD of documenting and complying with claim provisions (25:13).

The next chapter will focus on the process for aircraft acquisition, history of the F-16 RIW, and why the F-16 RIW was selected for study.

III. Case Study/F-16 Reliability Improvement Warranty

In view of the fact that the F-16 Reliability Improvement Warranty (RIW) program was the most comprehensive and complex application of a warranty ever attempted within DOD, it was selected as the focus for this thesis. Consequently, this chapter provides an overview of the major defense acquisition process and also discusses the necessary warranty planning. Also, to give the reader an understanding of the history and management structure of the F-16 RIW program, an overview is provided. Finally, the equipment which was warranted on the F-16 is identified.

Air Force Process for Aircraft Acquisition

Background. Aircraft acquisition follows the life cycle for Major Defense Systems Acquisition found in DOD directives 5000.1 and 5000.2. This process consists of five steps - the operational requirements process, the concept exploration phase, the demonstration/validation phase, the full-scale development phase, and the production/deployment phase (see Figure 3).

Since the purpose of an aircraft acquisition is to satisfy operational needs, it is necessary to examine how such needs are identified - the operation requirements process. First, the AF delegates this need identification process to the major commands, where mission area responsibilities lie. Major operating/using commands conduct continuous mission analyses (MAA) to identify deficiencies in

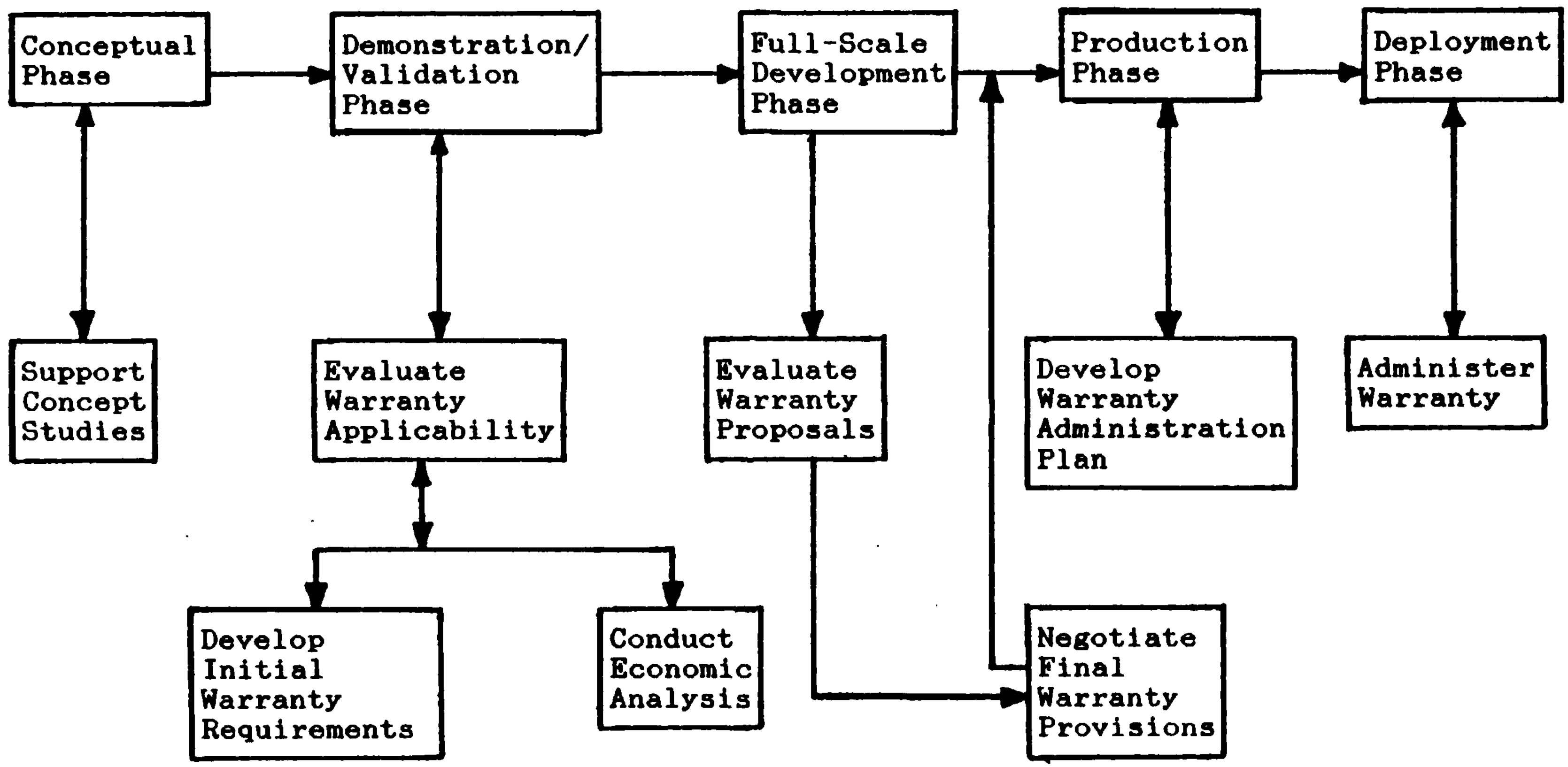


Figure 3. Warranty Planning During Defense Systems Acquisition Process (7:51)

current and projected capabilities. If these deficiencies cannot be resolved within a commands authority, the major command submits a Statement of Operational Need (SON) to HQ USAF. After determining whether a major system acquisition program is necessary, HQ USAF, prepares a Mission Element Need Statement (MENS). Approval of the MENS by the SECDEF formally initiates and authorizes a major program to enter into the Concept Exploration Phase, the first real phase of the acquisition process. In order to maximize the effectiveness of a warranty, it is important to consider the concept early in the life of a system's design. With early consideration, a decision to use a warranty has the greatest potential to affect equipment design and production, as well as the planning to maintain and support the warranted items (7:50).

Once the MENS and SON have been validated, the acquisition program competes among other needs in the Planning, Programming, and Budgeting System (PPBS) for funding to identify and evaluate alternative solutions. Warranties may be considered in these alternative solutions as a means of achieving stated goals and maintaining costs within resource limitations (7:50). Affordability is primarily determined by the PPBS which balances all validated programs against each other based on existing fiscal constraints. A program usually cannot proceed intc the Concept Exploration Phase without sufficient funding identified. After funds are identified, HQ USAF issues a Program Management Directive

(PMD) that provides the specific program requirements to the various commands.

After the alternative solutions are identified in the Concept Exploration Phase, the Demonstration and Validation Phase focuses on refining the selected alternatives through extensive studies/analyses, hardware development if appropriate, and limited test/evaluation. Also, during this phase, it is desirable to identify the basic requirements that a warranty should satisfy for future production effort. Trade-offs between different kinds of warranty provisions should be reviewed to determine if one kind of warranty is preferable to others. Further, in this phase, it is important to communicate to possible contract bidders the intention to consider a warranty since this consideration may affect system design (7:51). The final purpose of this phase is to validate one or more of the selected solutions and to provide a basis for deciding whether to proceed into the Full-Scale Development Phase.

The objective of the Full-Scale Development (FSD) Phase is to design, assemble, and test the system along with its support requirements to determine if the required operational capability can be achieved within expected or allowable costs. The output of this phase, at a minimum, is a preproduction system that closely approximates the final product including documentation needed to enter the Production Phase plus test results that demonstrate the system will meet the requirements. A selected development contractor will use

specifications and other technical documentation created during the Demonstration/Validation Phase to design the final system. At the end of the FSD phase, warranty proposals provided by the contractors should be evaluated and a final decision is made regarding what kind of warranty to use (7:51). Once testing and other Full-Scale Development actions are complete the last acquisition phase can begin.

The final acquisition phase is divided into two sub-phases - Production and Deployment. The production portion encompasses the time between the decision to produce a system is made and the time the last system is delivered and accepted. The objective is to efficiently produce and deliver effective and supportable systems to the operating units. Consequently, this sub-phase includes the production of all system hardware, spares, support equipment, data, software, etc to meet the above objective. After a production contract is signed, development of a warranty administration plan should begin (7:52). Finally, a system reaches the end of the acquisition process - deployment. This sub-phase begins when production items are delivered to and are used by the operational units. Often this occurs while a system is still in production which results in concurrent production and deployment. From initial deployment of a warranted system to the expiration of warranty coverage, procedures to strictly monitor and administer the warranty must be developed (7:52).

Reliability and Maintainability. One of the most significant items of continuing concern to the DOD is the need for improved reliability and maintainability of weapon system equipment (11). Hardware reliability is usually expressed by the term Mean Time Between Failures (MTBF), which is the average time interval between failures measured in hours (11). Maintainability refers to a design feature of a system, subsystem, equipment or component (11). It suggests the item is subject to being repaired in an established environment, under defined conditions, and within set time/cost restraints needed to meet established reliability requirements. In other words, maintainability does not define maintenance or repairs, but the ease which they may be accomplished (23:1).

A contractual technique used in the commercial market and that was used on a trial basis within the DOD as a means of implementing reliability/maintainability improvements is the Reliability Improvement Warranty (RIW) (23:34). The RIW trial period in the DOD was initiated following a 17 August 1973 memorandum from the Assistant Secretary of Defense for Administration and Logistics. An excerpt from the memo follows:

> In industry, extensive use is made of warranties, thereby establishing the manufacture's responsibility to provide a usable and available product during a period of time. To achieve this economically, many techniques have been employed by the supplier (i.e., more reliable products are designed; designs are improved to increase reliability during the initial operation phase; economic maintenance and repair procedures are developed). Accordingly, it is requested that a trial applica-

> tion of warranties be utilized in the acquisition and initial operational support of a number of Electronic Subsystems to help determine the scope and benefit warranties may have for the DOD, as well as effective management approaches. The warranty approach envisaged is one in which the supplier agrees to repair or replace malfunctioning or defective items of equipment during a specified period of time. [3:2-1]

The above concept was previously known as a failure free or standard warranty.

As the means of implementing such improvements in reliability and maintainability, the Air Force chose to use the contractual techniques of Reliability Improvement Warranty (RIW). Essentially, such a contract obligates the contractor to make improvements in the product so that scheduled improvements in reliability are met. Failure of the contractor to comply with the provisions of the contract lowers his profit either directly or indirectly. The objective of an RIW is to motivate and provide incentive to contractors to design and produce equipment with a low failure rate as well as low repair costs after failure due to operational/field use. It should be noted that an RIW is not a maintenance contract and does not require contractors to provide routine periodic upkeep, adjustment, cleaning, or other normal support (10). Further, an RIW does not cover components of a warranted item which are expected to need replacement under normal use during the term of coverage, such as filters, light bulbs, etc (10). Such items may be provided for by separate provisions in the contract but are not included in the RIW provision. In general, a RIW

provides for the repair or replacement of failed units as well as agreed to no-cost engineering changes (1:17,20,26).

The essence of a RIW philosophy is that during the period of warranty coverage contractors will be encouraged to improve the reliability and to reduce repair costs of their equipment through the mechanism of no-cost (to the government) Engineering Change Proposals (ECPs) (14:1-2). Once a fixed price is established for a RIW, the actual profit realized by the contractor is dependent upon the equipment's reliability and maintainability in service use, plus any improvements that the contractor can make in equipment reliability or maintainability to keep the number/ cost of repairs as low as possible (14:1-1,1-2). Consequently, a RIW results in a contractor focusing attention on reliability and maintainability efforts since through such a program the contractor can obtain greater profits (14:1-2). As a result, a RIW becomes a contracting technique by which the government derives the benefits of improved reliability and maintainability for each additional dollar that a contractor earns.

The concept of a RIW can be introduced at any point during the acquisition life cycle (described in the beginning of this chapter). However, normally the maximum benefit is expected by including the RIW contract provision at the time of award of the initial production contract for the system/ equipment (14:1-1). For new equipment, it is usually appropriate for the government to indicate to prospective contractors early in the development cycle that it plans to

consider such a warranty provision for inclusion in the contract at the time of initial production approval. In doing this, the government can motivate the contractor to ensure their equipment's reliability and maintainability are given appropriate attention at the time it is initially designed (11). The contractor's initial design of equipment can affect the subsequent repair or replacement costs (11).

The greatest value of a RIW contract provision is expected to be realized in the initial years of the equipment's field deployment. Consequently, after the equipment's reliability and maintainability have been satisfactorily demonstrated through field use, the government can then assess the cost effectiveness of the RIW (11). It should be emphasized that the terms and commitments required of the contractor, particularly for the initial warranty, should result in a reasonable balance between the contractor's risks and the degree of incentive needed to achieve the primary goal of system availability (10). The size and scope of the initial commitment should be determined by evaluating the uncertainties in future support cost and the risks involved to both the contractor and the government. The typical period of warranty coverage continues for three to five years (14:1-1).

F-16 Procurement History

The F-16 had its origin in the United States Air Force Lightweight Fighter (LWF) prototype program in 1972 (10). The first of two YF-16 prototypes made its official first

flight in February 1974. On 13 January 1975, the Secretary of the Air Force announced that the F-16 had been selected for full-scale engineering development. This acquisition contract for full scale development, production options, and data was awarded to General Dynamics in 1975 after a competitive source selection with Northrop. Original YF-16 requirements for an air superiority day fighter were expanded to give equal emphasis to the air-to-surface role, including provisions for radar and all-weather navigation capabilities. On 7 June 1975 a joint announcement by the four NATO countries of Belgium, Denmark, the Netherlands, and Norway confirmed their selection of the F-16 to replace their current F-104s hence establishing the F-16 as a Multinational Fighter Program (MFP) procurement.

The acquisition strategy for the F-16 included several provisions designed to reduce the system's life-cycle cost. Only one of these provisions is of interest for this thesis. This incentive for supportibility was that the government reserved the option to exercise Reliability Improvement Warranty (RIW) coverage with or without mean time between failure guarantees on any or all twelve major Line Replaceable Units (LRUs). A LRU is defined as "the first level of disassembly below the system level that would be carried as a line item of supply at base level" (29:3-4). It is a "black box" item which is usually removed from the aircraft and replaced as a single unit. Twelve LRUs were originally selected for RIW coverage; however, after a detailed cost

analysis this list was reduced to nine. On 3 February 1977, a separate contract was signed with General Dynamics placing these nine FLUs under RIW coverage. The nature of this separate warranty contract was that all units returned to the contractor during the warranty period would be repaired or replaced at no additional cost to the MFP nations.

F-16 RIW Structure (29:5-1 to 5-3)

This section provides background information of the broad management responsibilities of the organizations associated with the F-16 RIW program (see Table I).

> Program Management. The Directorate of Integrated Logistics Support, ASD/YPL, within the F-16 System Program Office, had program management responsibility for the F-16 RIW program. YPL was designated as the Office of Primary Responsibility (OPR) and was tasked to ensure the successful implementation of the F-16 RIW program. RIW management at Ogden Air Logistics Center (OO-ALC) was assigned to MMEA.

> Inventory Management. The F-16 Acquisition Logistics Division, OO-ALC/MMA, of the Directorate of Material Management at OO-ALC had inventory management responsibility for the nine RIW LRUs for the Multinational Fighter Program (MFP) nations of Belgium, Denmark, The Netherlands, Norway, and The United States. The tasks of provisioning, inventory management, and subsequent transition to organic maintenance were the responsibility of MMA. Further, since MMA assumed logistics responsibility following F-16 Program Management Responsibility Transfer (PMRT), MMA played a major role in RIW implementation. Therefore, YPL and MMA had a dual program management role.

> Procurement. The Procurement Contracting Officer (PCO) for the F-16 RIW contract, F33657-77-C-0062, was located within the Directorate of Procurement, ASD/YPK. The PCO was the final authority on all contractual matters related to the RIW contract. Further, the PCO was responsible for ensuring that the prime contractor, General Dynamics (GD), fulfilled its contractual obliga-

TABLE I

SUMMARY OF F-16 RELIABILITY IMPROVEMENT WARRANTY MANAGEMENT STRUCTURE

Organization	Responsibility
Directorate of Integrated Logistics Support (ASD/YPL)	Program Management
Acquisition Logistics Division (OO-ALC/MMA)	Inventory Management
Directorate of Procurement (ASD/YPK)	Contract Management
Directorate of Distribution (OO-ALC/DS)	Supply Management
Deputy Chief of Staff for Logistics (HQ TAC/LG)	Ensuring Contractor Obligations Fulfilled
Directorate of Multinational Programs (ASD/YPX)	Coordinating Appropriate Foreign Nation's Obligations
Air Training Command (HQ ATC)	Training Maintenance Personnel
Directorate of Deployment (ASD/YPD)	Successful Site Activation of F-16 Program
Air Force Plant Representative Office at General Dynamics, Forth Worth TX	Contract Administration
General Dynamics	Subcontractor Management

tions and was the only individual authorized to provide contractual direction to the contractor.

Configuration Management. The Directorate of Configuration Management, ASD/YPC, was responsible for all matters relating to configuration management of the nine RIW LRUs. Specifically, YPC was responsible for configuration identification, control, and status accounting. The RIW contract required the contractor to comply with configuration management procedures defined in the F-16 production contract (F33657-75-C-0310). Consequently, YPC was required to conduct careful surveillance of the production contract because of the unique relationship between that contract and the RIW contract.

Supply Management. The Directorate of Distribution, OO-ALC/DS, was responsible for the F-16 RIW policies associated with transportation, handling, packaging, and storage for USAF assets and coordination of these policies with the European Participating Governments (EPGs). This office supported OO-ALC/MMA which had worldwide asset responsibility.

Wing-Level Logistics. The Deputy Chief of Staff for Logistics (LG) within the Tactical Air Command Headquarters (HQ TAC) was responsible for ensuring that F-16 RIW operating activities fulfilled the government's contractual obligations. This included the activities associated with maintenance, data, supply, and transportation at the wing level.

EPG Management. The Senior National Representatives (SNRs) located within the Directorate of Multinational Programs, ASD/YPX, were responsible for coordinating their government's obligations under the RIW contract. Since the F-16 program was a five-nation shared program, the SNRs played a major role in RIW program management. All RIW decisions affecting the European Participating Governments (EPGs) required concurrence by the SNRs or EPG representative of the appropriate Multinational Working Group.

Training. Training of maintenance personnel for the organizational and intermediate levels of maintenance for the nine RIW LRUs was the responsibility of the Air Training Command (HQ ATC). However, YPL was responsible for an implementation training program designed specifically for RIW training for base maintenance, base supply, and Air Force Plant Representative Office personnel (AFPRO).

Site Activation. The Directorate of Deployment, ASD/YPD, was responsible for the successful site activation of the F-16 program. Each operating site had a Site Activation Task Force (SATAF) comprised of F-16 System Program Office personnel. The SATAF's responsibility included ensuring that problems associated with RIW implementation were channeled to the proper organizations for resolution and orientation of base-level personnel in the RIW concept plus special treatment of RIW LRUs required by the RIW contract were followed.

Contract Administration. The Administrative Contracting Officer (ACO) for the F-16 RIW contract is located in the Air Force Plant Representative Office (AFPRO) at GD Forth Worth. A delegation of authority memorandum between the Procurement Contracting Officer (PCO) and ACO assigned contract administration responsibilities for specifically defined areas. These areas included monitoring the general repair process of the RIW equipment and repair of non-warranted items.

Prime Contractor. The prime contractor's (GD) responsibilities included the effective management of subcontractors and subcontractor effort required in the performance of the RIW contract.

Past History

The F-16 RIW was the most comprehensive and complex application of a RIW ever attempted within the DOD (10). Although prior warranty programs have been undertaken, little operational experience has been accumulated. As a result, in many areas the F-16 broke new ground. The F-16 acquisition contract for full-scale development, production options and data was awarded to GD in 1975 after a competitive source selection with Northrop. The request for proposal included several provisions designed to reduce the system's life-cycle cost (14:1-2). One of these provisions required the contractors responding to the request for proposal to determine and propose a Target Logistics Support Cost (TLSC) (14:1-2). The

TLSC was used together with acquisition cost and other factors during source selection as the basis for award of the contract (14:1-2). Another provision to reduce life-cycle cost was that an award fee would be given to the contractor based on the relationship of measured Logistics Support Cost (MLSC) to TLSC where the former would be determined in a field test of an operational squadron (10). Finally, an additional incentive for supportibility was that the government included an option to exercise RIW coverage with or without mean time between failure guarantees on any or all of 12 major FLUs (first-level units or line replaceable units) (14:1-2,1-3).

Why these FLUs were Selected. These 12 FLUs were selected because they were expected to account for at least 50 percent of the F-16's logistics support cost (see Table II). The Target Logistics Support Cost (TLSC) for each FLU was determined from an abbreviated version of the AFLC Logistics Support Cost Model which included costs due to initial/replacement spares, on equipment maintenance, off equipment maintenance, and support equipment peculiar to the FLU. If Measured Logistics Support Cost (MLSC) was in excess of 25 percent of TLSC, the contractor was required to institute a correction of defects (COD) program (10). If MLSC was equal to the target as determined in a 3500 hour field test, then the contractor's profit would equal the target profit. The target profit was to be reduced by 30 percent of the cost difference if performance was below

TABLE II

EQUIPMENT CONSIDERED FOR THE F-16 RELIABILITY IMPROVEMENT WARRANTY PROGRAM (14:1-3,2-8; 33)

WUC	Nomenclature	Manufacturer
*14AAO	Flight Control Computer	Lear-Siegler Industries
*74BCO	Head Up Display (HUD) Processor	Marconi Avionics, Limited
*74BAO	Head Up Display (HUD) Pilot	Marconi Avionics, Limited
*74DAO	Inertial Navigation Unit (INU)	Singer-Kearfott Division
*74ACO	Radar Transmitter	Westinghouse Electric Corp.
*74ADO	Radar Signal Processor	Westinghouse Electric Corp.
*74AFO	Radar Computer	Westinghouse Electric Corp.
*74ABO	Radar Receiver	Westinghouse Electric Corp.
*74AAO	Radar Antenna	Westinghouse Electric Corp.
74CAO	Fire Control Computer	Delco
74EAO	Radar Electro-Optical Display	Kaiser Electronics & Aerospace
74EBO	Radar Electro-Optical Electronics	Kaiser Electronics & Aerospace

Note 1: (*) equipment were those selected for the RIW program.

Note 2: WUC is a unique identifying code assigned to FLUs. It is a combination of five alpha-numeric characters. The first two characters identify the system, the next two, the subsystem, and the fifth, the component (37:748).

target or increased by 30 percent of the cost difference if performance was above target (10).

However, the government reserved the option to place any or all of the 12 FLUs under a RIW contract, either with or without a MTBF guarantee. Any items placed under the RIW were to be removed from the TLSC-COD programs above. While this concept reduces a contractor's potential award fee available under the TLSC-COD, the contractor would receive an additional fixed sum for the FLUs selected for RIW. Futhermore, under a RIW concept a contractor assumes greater responsibilities for support.

F-16 RIW Contract. During 1976, the 12 FLUs were subjected to a cost analysis and in October of that year the System Program Office entered into negotiations with GD to extend RIW coverage to the four European Participating Governments (EPGs). As a result, in February 1977, a separate contract (F33657-77-C-0062) was signed with GD in which nine FLUs (see Table II) were selected for RIW coverage for all five MFP nations. The RIW provided that all warranted units returned to the contractor during the warranty period would be repaired or replaced at no additional cost to the MFP nations (1:17). The nine FLUs were warranted for a period of four years or 300,000 flying hours, whichever occurred first (1:19). The four-year period began upon acceptance of the first production aircraft to be delivered to an operational site -January 1979 to December 1982 (1:19). The flying hours applied to the first 250/192 USAF/EPG

production aircraft (1:19). In the event that less than 250,000 flying hours were accumulated at the end of the warranty period, the price of the contract would be adjusted downward in accordance with the formula specified in the F-16 RIW contract (1:19).

IV. Assessment of Weapon System Warranties

This chapter focuses on the feasibility of obtaining the theoretical information identified in chapter two for assessing the costs and benefits of weapon system warranties. Specifically, the information required to evaluate and measure warranty costs and benefits is discussed along with examples of data obtained from the F-16 Reliability Improvement (RIW) program. First, the nature of the information necessary to evaluate warranty costs and benefits is reviewed. The second section discusses the information required to evaluate the warranty cost of the F-16 RIW contract. Next, the problems involved in measuring warranty costs are considered along with some of the problems found in obtaining these costs. Finally, in the last section, the evaluation and measurement of F-16 RIW warranty benefits is addressed.

Theoretical Considerations Reviewed (23:2-5)

Gandara noted, in his report Reliability Improvement Warranties for Military Procurement, that most weapon system contracts fail to levy a contractor with a major portion of the life-cycle cost for their equipment. Consequently, it is widely believed these contractors pay inadequate attention to equipment reliability (23:2). Figure 4 shows the economic situation for both the contractor and the government under normal procurement practices by "illustrating the typical contractual distribution of burdens and risks" (23:2). This

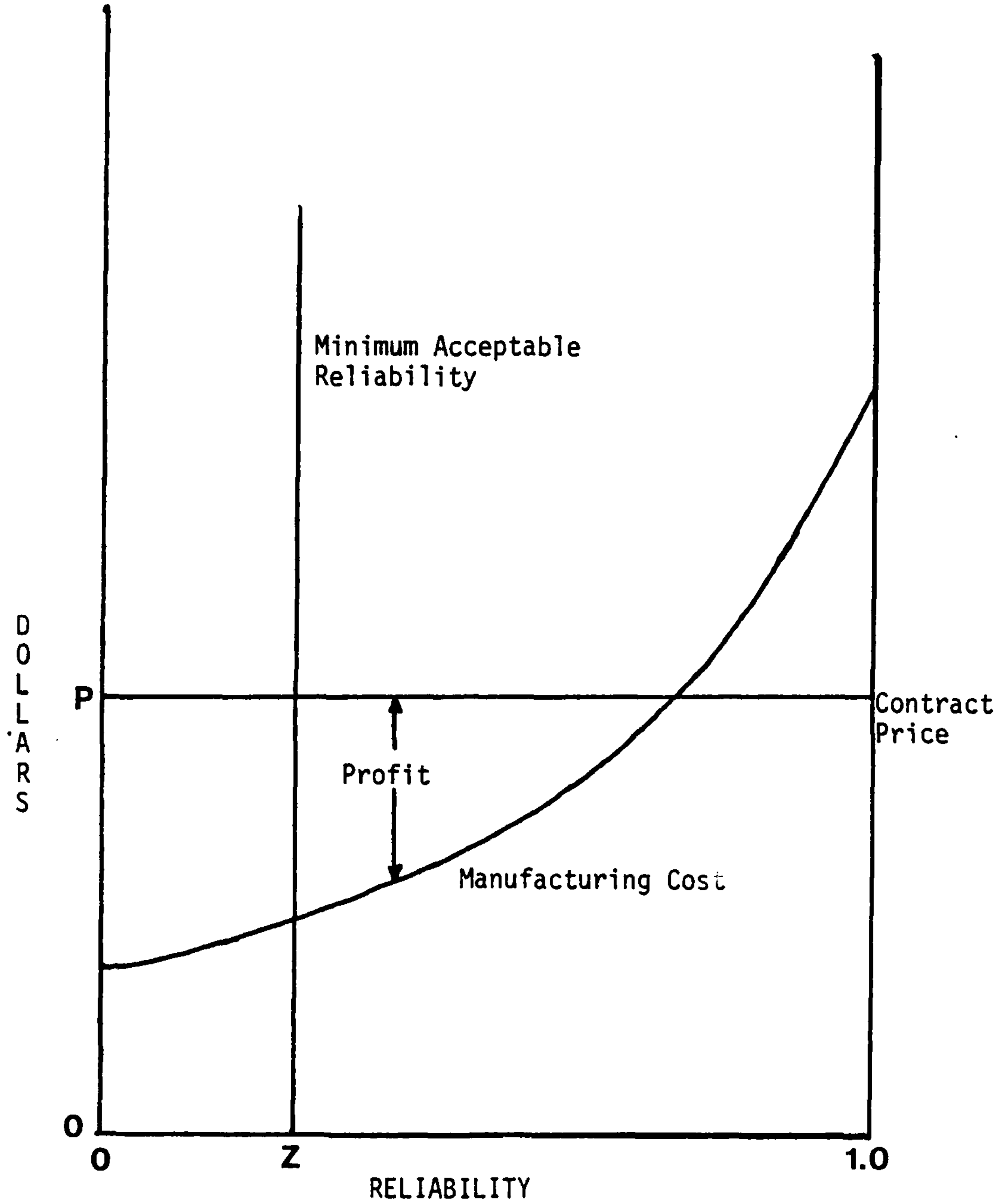


Figure 4. Cost Versus Reliability Before a Warranty (23:3)

figure represents the manufacturing cost of equipment as a function of equipment reliability and depicts the "usual costs incurred up until delivery of the equipment from the contractor to the using command" (23:2). Once the equipment is delivered, DOD "exclusively and explicitly bears the costs of supporting the product" (23:2). If a contractor disregards all other factors and considers manufacturing cost strictly as a function of equipment reliability, he can reduce this cost by reducing the quality of components, testing, inspections, or a number of other aspects of the program. These other reductions will also reduce equipment reliability. The distance between the fixed-price contract line (p) and the manufacturing cost curve represents the profit at any achieved level of reliability. Therefore, at any point on the manufacturing cost curve a contractor is inherently motivated to move to a lower-cost, lower-reliability point on the curve. "Moreover, to the extent that the contractor has no competition in providing replenishment spares and support equipment, he has even less incentive to achieve more than minimum reliability" (23:2).

Conversely, Figure 5 illustrates the same situation but assesses the impact with a warranty. Now a contractor must consider in his price not only manufacturing costs but also the cost of meeting warranty claims. Therefore, "all other things equal, improved system reliability reduces warranty claim costs" (23:2). The contractor's total cost is now represented by the U-shaped curve in Figure 5. This curve is

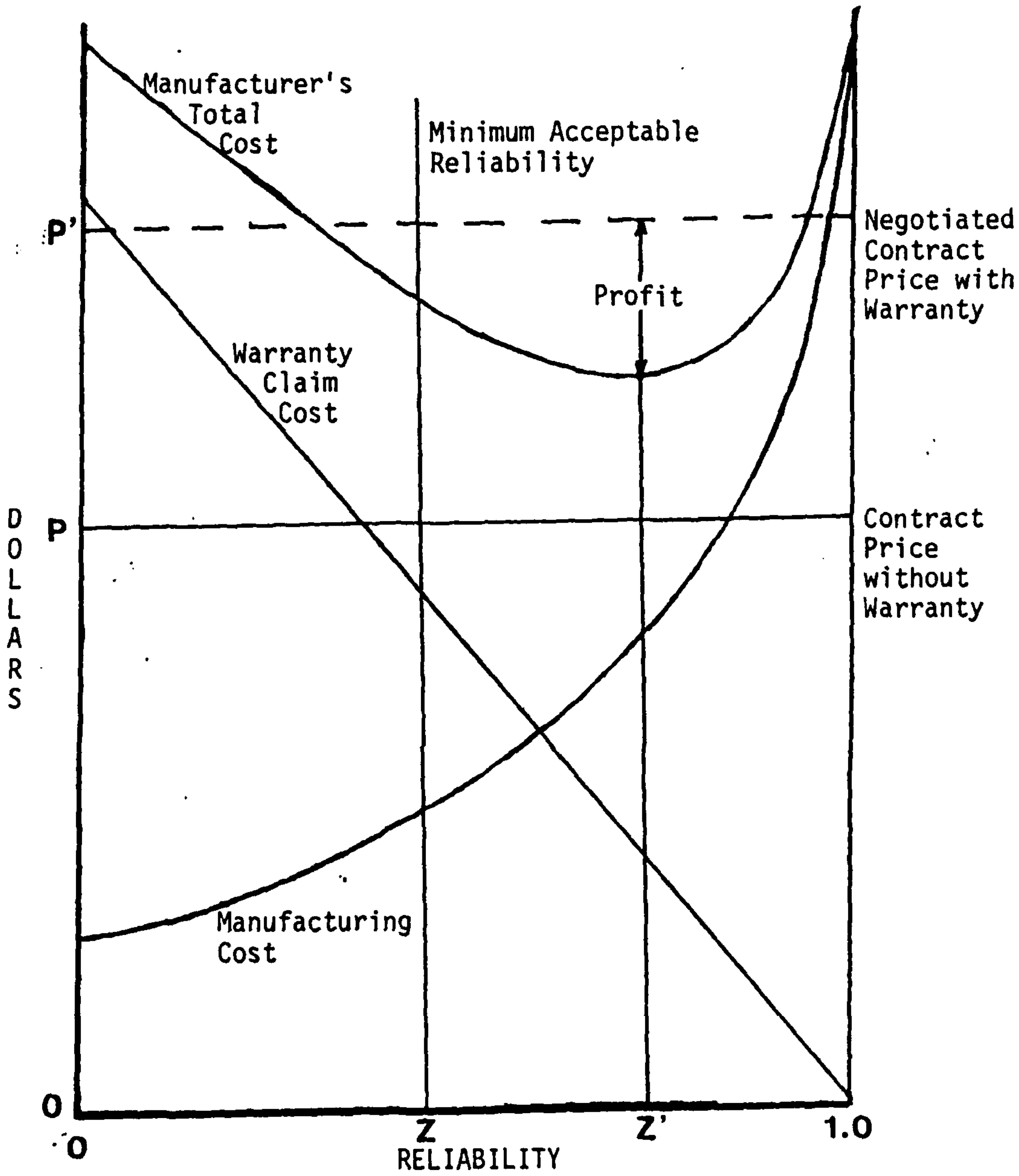


Figure 5. Theoretical Economic Incentive With a Warranty (23:4)

the vertical summation of the manufacturing and warranty claim cost curves. Profit is now represented by the distance between the horizontal negotiated contract price with a warranty (p') and the U-shaped total cost curve. Therefore, it can be seen that in theory a contractor is not motivated to move back down the manufacturing cost curve since below some optimum reliability (z') profits would decrease instead of continuing to increase. "The cost to DOD of this improvement, on the surface, will be the amount of any negotiated upward adjustment of the contract price (difference between z' and z) necessitated by the redistribution of burden and risk."

Additionally, location on a given manufacturing cost curve and the shape of that curve is not necessarily constant over the warranty period. During and even after production a contractor has the opportunity, based on field experience, to change his location on or respond to a change in the shape of the manufacturing cost curve by developing Engineering Change Proposals (ECPs) that improve the reliability characteristics of equipment. Such a change might occur because the contractor has revised his estimate of the profit maximizing level of reliability or because advance in technology have lowered the costs of producing reliability. The U-shaped manufacturer's total cost curve is a "commonly accepted but simplified valid economic description of the reliability incentive inherent in a fixed price warranty" (23:2). However, it is not the only shape possible from the summation of the

manufacturing and warranty claim cost curves. According to Gandara:

> Depending on the slope of these two curves, it is also possible to produce a manufacturer's total cost curve that is continually rising or continually declining over the relevant region. Assuming a fixed contract price, in the first case maximum profit would be obtained at the minimum acceptable reliability and in the second case maximum profit is obtained at maximum attainable reliability. [23:5]

Only if the slopes of the manufacturing and warranty claim cost curves are known can a profit-maximizing contractor's behavioral response to a warranty be predicted. "Identification of the proper manufacturer's total cost curve and consequently the probable contractor response is more difficult when an item to be procured is still in the concept or design stage" (23:5). This is due to the unknown relationship between reliability and manufacturing costs.

Evaluating Warranty Costs

As previously discussed in chapter two and in the above section, the costs associated with a warranty must be identified and defined in order to be able to determine the cost-effectiveness of the warranty. These costs are separated into two types - explicit and implicit. Explicit costs were defined as the manufacturer's total cost at a set level of reliability including the manufacturer's profit. On the other hand, implicit costs of a warranty were defined as the administrative cost incurred by DOD to enforce legal warranty claims.

As illustrated in Figure 5, a manufacturers' total cost is a function of the manufacturing and warranty claim costs. Consequently, a manufacturer can make trade-offs between these two costs. Additionally, the DOD fixes the amount of revenue a manufacturer can receive; therefore, in order to maximize profit the manufacturer will strive for the cost which corresponds to the minimum point on the total cost curve.

In order to make the best decision regarding warranties, it is necessary to evaluate warranty costs to the manufacturer and DOD for warranty coverage. First, for the manufacturer's costs, actual cost to the manufacturer of a failure, number of failures which occur at a given level of warranty coverage, and manufacturing cost of building reliability into a product must be determined. Second, for DOD costs, the amount paid for the warranty coverage (explicit) and the internal cost of documenting/complying with the warranty claim provisions (implicit) must be determined.

Before attempting to determine manufacturing and DOD costs, two terms need to be defined - failure and reliability. Defining a failure is therefore a crucial determinant of a contractor's required performance. "Failure" is a generic term, used in the model in chapter two, to describe a condition the manufacturer is responsible for correcting. Therefore, when discussing warranties, "failure" can take on a number of meanings. It could mean a complete breakdown in the operation of an item, or potential breakdown of an item.

For a partial breakdown an item may still be operational but not at 100 percent capacity. Consequently, unless "failure" is explicitly defined in the contract, there could be problems in determining who is responsible for fixing the item. On the DOD side, any breakdown of an item should be fixed by the manufacturer. From the manufacturer's point of view, any "failure" costs money and decreases profit. As a result, the manufacturer may be reluctant to fix the item. A warranty clause can alleviate the ambiguity of the term "failure" by describing the conditions under which a claim can be made. Also, the warranty claim can make the responsibility for fixing the item legally binding. The warranty clauses for the F-16 program provide an example of the diversity of the term "failure".

The definition of a "failure", for the F-16 Reliability Improvement Warranty, includes all units removed from operation because of a determination that they do not perform in accordance with the warranty provisions in the contract. In other words, the contractor's primary obligation under an RIW is to repair or replace, at its own option and for a fixed price, items furnished under the contract that are found to be defective in design, material, or workmanship. Inevitably, some units removed by the government and returned to the contractor will be found to be free from any defect. These are termed non-verified failures. Further, a warranty does not obligate the contractor to fix or replace all failed units. Failure due to certain events outside of the control

of the contractor are excluded from coverage and in the F-16 RIW include (1:18):

1. fire
2. explosion
3. aircraft crash
4. submersion
5. acts of God (flood, etc.)
6. improper installation or maintenance by government personnel
7. accidental tampering or willful mistreatment by government personnel
8. enemy combat action

The government usually negotiates a separate contract with the manufacturer to cover repair or replacement of units excluded from warranty coverage because of one of the above reasons.

"Reliability" is also a generic term, used in the model in chapter two, to describe the quality of a product. It is defined by Air Force Manual 11-1 as the probability that an item will perform a required function under specified conditions, without "failure", for a specified period of time (16:). When discussing warranties, "reliability" can take on different meanings. Therefore, it is important when measuring the costs of warranties, that the term be defined for the specific warranty being evaluated.

Hardware reliability, under an Reliability Improvement Warranty program such as the F-16, was expressed by the term Mean Time Between Failure (MTBF) which is defined as the total operating hours accumulated during a specified period on all units divided by the total number of failures of all

such units (1:32). For the purpose of MTBF measurement, failures included all repair or replacement actions performed by the contractor except the following:

1. any repair or replacement determined to be excluded from coverage (items 1 thru 8 above) [1:32]
2. any item returned for repair or replacement that tests good at the repair facility (non-verified) [1:32]

An RIW is a fixed price contractual provision intended to motivate a contractor to both design and produce systems with inherently low failure rates and repair costs, and improve system reliability even after the system is deployed. Before the advent of RIW's, the risks associated with deploying state-of-the-art technology was borne by the Air Force. These risks include reducing system life-cycle cost, identifying design/production deficiencies, and accurately predicting future costs and failure rates. Poor reliability brought on "high operation and support costs or reduced asset availability" (29:3-2). With RIW's, now the risks are shared by the Air Force and contractor.

Table III provides a list of the items that were warranted on the F-16 program. This was the only equipment warranted under the F-16 program. The contractor agreed that he would repair or replace all First Line Units (FLUs), identified in Table III, that fail. Seven of these FLUs were covered by a RIW without a specified MTBF to meet. This meant that their actual warranty coverage was equivalent to the standard warranty rather than a RIW warranty guarantee.

However, two of the FLUs (identified by asterisks in

TABLE III

EQUIPMENT WARRANTED UNDER THE F-16 RELIABILITY IMPROVEMENT PROGRAM (14:1-3,2-8)

WUC	Nomenclature	Manufacturer
14AAO	Flight Control Computer	Lear-Siegler Industries
74BCO	Head Up Display (HUD) Processor	Marconi Avionics, Limited
74BAO	Head Up Display (HUD) Pilot	Marconi Avionics, Limited
74DAO	Inertial Navigation Unit (INU)	Singer-Kearfott Division
74ACO	Radar Transmitter	Westinghouse Electric Corp.
74ADO	Radar Signal Processor	Westinghouse Electric Corp.
74AFO	Radar Computer	Westinghouse Electric Corp.
74ABO	Radar Receiver	Westinghouse Electric Corp.
74AAO	Radar Antenna	Westinghouse Electric Corp.

Note 1: WUC is a unique identifying code assigned to FLUs. It is a combination of five alpha-numeric characters. The first two characters identify the system, the next two, the subsystem, and the fifth, the component (37:748).

TABLE IV

MEAN TIME BETWEEN FAILURE GUARANTEE ON THE F-16 RELIABILITY IMPROVEMENT WARRANTY PROGRAM (1:33)

FLU Identification	Calendar Period from Acceptance of First Production Aircraft to an Operational Unit (January 1979)	Unit MTBF
74ACO Radar Transmitter	Period 1: 1 thru 12 months	238 hours
	Period 2: 13 thru 24 months	297 hours
	Period 3: 25 thru 36 months	318 hours
74BCO Head Up Display (HUD) Processor	Period 1: 1 thru 12 months	325 hours
	Period 2: 13 thru 24 months	470 hours
	Period 3: 25 thru 36 months	500 hours

Table III) were guaranteed to achieve a MTBF equal to or greater than those shown in Table IV. The rationale behind having MTBF guarantees on only two of the FLUs was based on an analysis of the technical aspects of all nine items. The final decision of which FLUs would have MTBF guarantees was made by the Deputy for the F-16 at that time, General Abrahamson (10). A detailed explanation of this decision can be found in the official F-16 RIW contract file (F33657-77-C-0062) located in the contract distribution division of the Deputy for Contracting and Manufacturing at the Aeronautical Systems Division.

A MTBF guarantee is often used in conjunction with a RIW (29:3-2). Again, it provides an incentive for the contractor to increase reliability and reduce support costs. For each unit, identified in Table IV, the contractor was required to make semi-annual measurements of the unit MTBF achieved (using the above definitions of MTBF) over the previous six

month period. These measurements were based on the performance of all units delivered under the contract. The contractor's obligation with respect to the unit MTBF guarantee was to terminate when two consecutive measurements yielded unit MTBF values that exceeded the guaranteed unit MTBF values for the 25 through 36 month period identified in Table IV. In no event was the contractor's obligation to terminate earlier than 18 months after initial delivery of the FLUs or continue beyond 36 months from that date.

In the event the measured unit MTBF for any period was less than guaranteed unit MTBF (in Table IV) for that period, the contractor was required to furnish the following to the government at no additional costs (1:34):

1. Engineering analysis to determine the causes of nonconformance of MTBF.
2. Corrective engineering design changes.
3. Modification of all units and technical data, as required at contractor's expense.
4. Additional unit spares as needed by the government on a consignment (no-charge loan) basis until guaranteed unit MTBF is achieved.

Measuring Warranty Costs

Keeping the above definitions of failure and reliability in mind, an attempt was made to locate the information required to measure warranty costs. Along these lines, Dave Rehorst, a contract price analyst for the Aeronautical Systems Division Directorate of Pricing, pointed out that an obstacle is that even if the required information is avail-

able, it can not be found in one central place or office. Much of the data has even been discarded to make room for current program files (44).

To measure warranty cost, DOD must obtain or estimate the costs to the manufacturer and the costs to DOD. A manufacturer encounters two types of cost - the cost of paying warranty claims and the cost to avoid paying those claims by building a more reliable product. Theoretically, according to the model in chapter two, a manufacturer will build a better product up to the point where the savings in warranty claim payments are just offset by the increased cost of building a more reliable product. In order for DOD to negotiate effectively with the contractor regarding the price of a warranty, one needs to know the impact of the warranty on his total costs relative to the prior non-warranty position.

Manufacturer Costs. To measure the manufacturer's cost for warranty coverage, data in three areas are required - actual cost of a failure, number of failures, and the cost of building reliability into the product.

Actual Cost and Number of Failures. The first two types of information required to measure warranty cost to the manufacturer, the actual cost of a failure and number of failures, are similar and will be discussed together.

Data Necessary. The actual cost and number of failures will depend on the contract warranty clause and the contractor's obligations. These obligations can include the

costs to remedy or take corrective action when a warranted failure occurs. Also, contractor administration costs are incurred just by having a warranty on an item. These costs include preparing warranty data reports for the government, and also the cost of a program to administer warranty claims (6:4-13; 27:117).

Remedies are the way in which a contractor will correct a failure and are specified in the contract provisions. There are three basic remedies a contractor can take, as described in a warranty handbook compiled by Arinc Research Corporation for the Defense Systems Management College (6:4-11):

1. a contractor is required to take such corrective action as necessary to repair, replace, and/or redesign at no additional cost to the government.
2. a contractor is required to reimburse and costs reasonably incurred by the government in taking necessary corrective action itself.
3. a contractor provides an equitable adjustment in contract price in the event of a failure.

The F-16 Reliability Improvement Warranty Program required that the implement the remedy described in 1. above.

A contractor is sometimes required to provide reports pertaining to warranty corrections. These reports are used by the government to implement certain elements of a warranty such as turnaround time, to maintain appropriate inventory/configuration control, and to assess the effectiveness of the warranty (6:4-13). More extensive forms of incentive warranties may require that a contractor provide an assessment of the warranty effectiveness through an annual report

to the government. On the F-16 Reliability Improvement Warranty, required warranty data reports are identified in Exhibit "A" of the contract (F33657-77-C-0062). As an example, the type of report generated on the F-16 was a semi-annual warranty data report. With this report, General Dynamics provided data on the actions taken under the warranty including the total repair manhours, cost of parts used for repair, and number of warranted failures. The report also provided the item nomenclature, serial/part number, total operating time with actual MTBF, reported problem, and number of days to satisfy the claim.

Finally, a contractor's program to administer the warranty claims involves office personnel, freight, receiving, shipping, engineering, and manufacturing functions. Unless an item is to be corrected by sending mechanics to the site, separate areas to work on repairs must be established. Also, a storage area for replacement parts for anticipated failures may be required (27:117). In a conversation with Carolyn Bowling, Contracting Officer for the F-16 RIW, I was told that General Dynamics as the prime integrating contractor was responsible for the overall management, repair disposition, vendor direction, coordination with the Air Force, and reporting on the warranty program efforts (10). In addition, warranted item repair facilities were located at the vendor plants and overseas (10).

<u>Methods of obtaining the Data</u>. For DOD to determine the number of failures and the manufacturer's cost

of a failure, two strategies exist with regard to timing. One involves the need for data prior to contract award in order to perform cost-benefits analyses and is the basis for negotiating a warranty price with the manufacturer. The second involves obtaining the data after the warranty period to help gage the profitability of the warranty contract to the manufacturer. Such information is very important to future negotiations.

Prior to contract award, it is common procedure for DOD to estimate the manufacturer's cost of a failure using an engineering analysis of projected number of failures based on the remedy cost of those failures (6:7-4 to 7-7). Also, according to Bowling, many times a manufacturer's warranty cost is provided by the contractor during his proposal submission (10). DOD uses this figure as a starting point to acquire a warranty on an item. In evaluating a contractor's proposed warranty price, consideration must be given to the disclosure requirements of Public Law 87-653 which states a contractor is responsible for submitting "cost or pricing data to certify that, to the best of their knowledge and belief, the cost or pricing data submitted is current, accurate and complete" (27:87). This requirement extends to all negotiated contracts, modifications, or subcontracts over $100,000 and included the warranty price as well as to all other elements of a proposal. "The Act contains exemptions which can be rather complex in application, but in general

procurements are exempt from the Act if they involve (27:88-89):

1. adequate price competition,
2. established catalog or market prices,
3. prices set by law or regulation; and
4. secretarial wavier.

Generally, this information has been satisfactory; however, no warranty literature could be found that evaluated the accuracy of this cost pricing data.

Further, the requirements of Public Law 91-379 (Cost Accounting Standards), needs to be considered in pricing a warranty proposal (2:41). In any discussion of contract costs it is necessary to understand the term "disclosure requirements". "One must first resolve the question, what is cost or pricing data" (27:88)? Cost or pricing data is defined as "all facts as of the time of price agreement that prudent buyers and sellers would reasonably expect to affect price negotiations significantly (27:88). Basicly a "fact" can be verified. "Judgments are not facts, are not subject to verification, and therefore are not subject to disclosure" (27:88). If there is any question about whether a proposal properly complies with the contractor's disclosure statement and approved accounting procedures, this should be pursued with the contractor and/or the contract administration office to assure compliance. The rule of consistency in accounting for costs is still valid (27:118). However, DOD "must be careful that requesting a contractor to account for warranty costs in a certain way may have the effect of the government requesting a change in the contractor's accounting system

which could be contrary to his disclosure statements" (2:41). Compliance with a warranty could require a higher level of costs than were incurred in the past or could require an element of cost not previously incurred (cost for a warranty manager or bonded storage area); in such cases it is reasonable to include such costs. For many contractors, since weapon system warranties have only recently become mandatory, there is a lack of a historical warranty data base to support their proposals.

Once the period of warranty coverage has elapsed, if there was a requirement in the contract to submit data for the actual cost and number of failures, this data could be used to evaluate the warranty. This was the case with the F-16 Reliability Improvement Warranty. General Dynamics developed and maintained a semi-annual warranty data report for each returned item consisting of the following (1:28):

1. date received by contractor
2. serial number
3. condition of unit based on initial inspection
4. failure mode
5. probable failure cause
6. action taken for repair
7. manhours expended by labor category
8. parts and material usage
9. test results
10. date stored in secure storage area

Table V provides a six month summary, for the period July 1980 thru December 1980, on each warranted F-16 FLU consisting of the quantity of items returned, exclusions, non-verified failures, warranted failures, and units in repair. The information in this Table could be used to determine the number of warranted failures for each FLU over the warranty

TABLE V

FIRST LINE UNIT REPAIR SUMMARY (24:4)

Unit	Qty of Units Returned	Qty of Exclusions	Qty of Non-verified Failures	Qty of Warranted Failures	Qty of Units in Work
Flight Control Computer	112	1	23	77	11
Head Up Display (HUD) Processor	68	0	27	34	7
Head Up Display (HUD) Pilot	72	14	8	46	6
Inertial Navigation Unit (INU)	149	2	19	115	13
Radar Transmitter	130	0	18	94	18
Radar Signal Processor	78	1	12	52	13
Radar Computer	79	0	3	68	8
Radar Receiver	143	0	5	122	16
Radar Antenna	151	1	11	118	21

Note 1: F-16 Reliability Improvement Warranty Repair Summary for the six month period beginning 1 July 1980.

period (four years) if all eight semi-annual warranty data reports could be located. Also, the report provided a unit summary for each warranted item. These unit summaries provided additional information on each FLU which included, but was not limited to, total repair manhours expended by labor category and cost of repair parts. For example, the cost of repair parts on the Flight Control Computer for the period July 1980 thru December 1980, was reported as $523. This figure appears to be a very low number for a six month period which leaves doubts in ones mind about the data. Standard wage rates for each labor category were not provided. Since standard labor rates for the appropriate labor hours are not provided, it would be difficult to determine the actual cost to the contractor of making repairs. However, if the standard wage rate for each labor category was known, then one could determine the actual cost of warranty claims (for each FLU) to the contractor. This would be possible if all eight semi-annual warranty reports could be located.

An attempt was made to locate these reports by contacting the F-16 Program Office, Air Force Logistics Command Material Management Offices, General Dynamics, and the Product Performance Agreement Center Library. Only two of six semi-annual could be located from these sources. In a conversation with Carolyn Bowling Contracting Officer for the F-16 RIW, she stated that the reports were available immediately after the warranty period elapsed but she did not know

where within the government they were now or even if they had been saved (10). She suggested the reports should be available in General Dynamic's or their vendors repositories. In a further attempt to locate these reports, Richard Newhouse Program Manager at General Dynamics stated that the records, associated data, and documentation were only available to the government during the warranty period or for a year thereafter according with the provisions of the contract (40). In other words, General Dynamics was only obligated to make the information available during this time period. Consequently, if General Dynamics or their vendors still have and were willing to provide this information, they might require additional compensation. However, Newhouse further indicated that because four years have passed since the end of the warranty period, the reports probably have not been retained by General Dynamics or their vendors either.

After the expiration of a warranty, if there was not a contractual requirement to submit information on the cost of a failure and number of failures, it would be even more difficult to obtain this data. A suggested method to obtain the data is to use the Air Force Maintenance Data Collection System (MDCS) which is designed to provide useful maintenance data to all management levels within the Air Force. The first step would be to determine the number of failures for units covered by the warranty. Second, estimate the cost of the failure using labor and material cost plus the cost of replacement parts. Finally, the estimates generated could be

used as the cost of warranty claims to evaluate the warranty. The major problem with this method is the Air Force MDCS has often been criticized as an inaccurate and incomplete source of maintenance data (6:4-4; 36). In fact, in 1983 "the GAO issued a report on the inadequacy, inaccuracy, and inefficiency of the USAF's MDCS" (38:197). One problem with the system is it does not allow for the direct comparison of contractually specified MTBFs. Only Mean Flight Hours Between Failure (total flying time of equipment for a specified time interval divided by the number of relevant failures during that interval) are tracked, not MTBF. The calculation of a MTBF requires that total operation time, both ground and flight be known; the MDCS only tracks flight times. Another shortcoming of the MDCS is it includes many failures which would not be counted as failures in formal reliability demonstration testing (9:466). Examples include accidental damage, tire wearout, and minor adjustments (9:466). In addition, other contractor claim costs, such as preparing reports, administration of the warranty, and operating repair facilities are not considered. Accordingly, this would result in an underestimated warranty claim cost for the contractor if the MDCS was used.

Cost of Building Reliability. The last type of information required to measure warranty cost to the manufacturer is the cost of building increased reliability into a product. As previously discussed, reliability refers to the probability that an item will perform a required function

under specified conditions, without a failure, for a specified period of time. Further, reliability must be explicitly defined in the provisions of the contract.

Data Necessary. "Design is an evolutionary process involving the application of various technologies and methods to produce an effective system output" (8:192). The process of determining and designing a given reliability level into a product is the application of scientific and engineering efforts (8:6,192). This process begins early in the conceptual phase of a weapon system acquisition cycle. The weapon systems specifications are the output of the above scientific and engineering efforts (8:193). Immediately preceding and during the production phase, changes in a weapon systems's reliability are accomplished using additional techniques such as quality control, production changes, or redesigns of the system (8:282,284). For weapon system, such as the F-16 aircraft, DOD sets the level of reliability requirement. During the early acquisition phases, contractor engineering efforts integrate safety, reliability, maintainability, and cost into the weapon systems design. The goal is to achieve an acceptable balance between operational, economical, and logistical factors (8:192). Once a weapon systems design is established, increases in reliability are realized through Engineering Change Proposed (ECPs).

ECPs are the technique by which a contractor changes reliability once design for the weapon system is established. In theory a contractor will not be motivated to improve

reliability of the item when it is not to his economic advantage to do so. A contractor is ultimately motivated by the economic benefit of increased sales and profit. Consequently, under a fixed price warranty contract such as on the F-16, if it is more costly to institute a fix for a failure than to continue repairing the failure a contractor will continue repairing rather than implement a redesign. The absence of ECPs then only reflect sound economic judgement on the part of the contractor. On the other hand, the above statement assumes a contractor has perfect information to begin with and that available technology does not change. If this is not the case, then it is possible that after a period of time a contractor recognizes a new level of reliability as being the profit maximizing one and as a result initiates an ECP.

When an MTBF guarantee is added to a warranty (the radar transmitter and head up display processor on the F-16), the contractor now has an added economic incentive. If the MTBF is not achieved, the contractor is also responsible for engineering analysis, design changes, modification of the item, and for possibly providing loaner spares until the MTBF is met. This added liability could increase the contractor's costs substantially. As a result, a contractor is more motivated to improve reliability through such means as failure analysis, design changes, and modifications.

As discussed in chapter two, a contractor can make trade-offs between manufacturing and warranty claim costs.

Therefore, the manufacturing cost of building increased reliability into an item is needed to measure warranty costs. In order to determine this manufacturing cost, detailed engineering and financial information with regard to the production process is required (25:10).

<u>Methods of Obtaining the Data</u>. Prior to a warranty, data pertaining to a contractor's cost of production are provided by the contractor and estimated by the government. This information is used to establish the basis for negotiation of a proposed contractor's price (10; 27:30).

A contractor, in his proposal, describes the manner in which a product will be produced. Additionally, to justify the price, a contractor intends to charge, detailed estimates of proposed or anticipated costs are described. If a contractor has not produced similar products before, extensive technical analysis and consultation with subcontractors or suppliers is used to develop the production costs. On the other hand, if a contractor has experience in making similar products and his cost accounting information is sufficiently current so reliance can be placed on it, production cost can be estimated using his accounting system (27:84-89).

The government prepares independent cost estimates as the means to compare the contractor's proposed price (27:30). These government estimates are prepared using engineering analysis of the item to be procured and are supported with any historical data the government has on the cost of producing similar items (27:30). On the F-16 RIW program,

historical manufacturing cost and engineering data was available for each of the nine FLUs since these items were to be off-the-shelf equipment modified for the F-16 requirements (10). This data is used by specialists in the Directorates of Program Control, Engineering, Logistics and other offices to develop the government estimate for negotiations (44). During negotiations these estimates are used by contract negotiators in support of the contracting officer for determining what the contract price will be (44). Although this data is used to determine estimates for production cost, it does not provide any insight to the manufacturing cost portion of building increased reliability into a product.

After the warranty period has elapsed, the type of manufacturing cost data available to the government are the result of the requirements of the contract. However, the barrier to research in the area of determining the cost of building increased reliability into a product is the nature of the data required. Fixed warranty costs are an intrinsic part of a contractor's overhead accounts. These data are proprietary and are not usually released outside the firm. Consequently, the cost to the contractor of building increased reliability into a product would be difficult to obtain from data the Air Force currently has available since this information is reported as the total manufacturing cost to build each piece of equipment. It is not broken down into figures that report the change in manufacturing cost due to some increased level of reliability.

For example, on the F-16 aircraft contract, a Cost Performance Report (CPR) was generated monthly by the contractor and provided actual manufacturing costs for each FLU. The problem with trying to use the data from the CPR is the dollar amounts are based on the contractor's cost accounting system and the method of cost allocation must be understood. In order to assess the incremental cost of building increased reliability into equipment, an analyst must completely understand not only the technology involved but also the contractor's cost accounting system. This can be complicated since contractors allocate cost differently (as long as consistency is maintained) and sometimes change their cost accounting system (48).

Other contractual techniques besides the manufacturing process can impact the reliability of equipment (10; 11; 44). These techniques include, but are not limited to, Engineering Change Proposals (ECPs), award fees, and increased quality control inspections (10; 44; 48). For example, an award fee is a separate contractual incentive used (in addition to warranties) to improve equipment reliability. With an award fee, a program manager evaluates achieved reliability with specified reliability levels in the award fee plan and awards additional funds to the contractor based on his performance. A distinction between the incentive applied by a Reliability Improvement Warranty and those provided by other contractual techniques is that the amount of profit is contractually fixed at production award for a RIW. This is different from

an award fee which increases profit in pre-defined increments for realized improvements in reliability after production has begun.

Additional methods to obtain data for the manufacturer's cost of building reliability into his equipment could include personally contacting the contractor for the data or requiring the data in a specified format to be provided by the contractor as a condition of the contract (48). Nevertheless, the former method would require a rapport between the contractor and the analyst in which the contractor is willing to provide the data (44). The latter method would require additional cost to the government corresponding to the value of the data; however, since the information would aid the Air Force in negotiating the warranty price a contractor would naturally be reluctant to disclose it. In any event, the data is usually contractor proprietary which further complicates any efforts to obtain this data. The point is, in negotiating the price of a warranty, DOD needs to know the impact of the warranty on the contractor's total cost but the incremental manufacturing cost portion of building increased reliability appears to be hidden (48).

DOD Costs. In order to determine the change in DOD costs that result from a warranty, one must first evaluate the price of the warranty which is a function of the cost to the contractor - the manufacturing cost of building increased reliability and the warranty claim expenses. The next step is to evaluate the cost to the government of enforcing the

warranty. To measure the DOD cost for warranty coverage, data in two areas are required - explicit and implicit costs.

<u>Explicit Cost</u>. The explicit cost to DOD of warranty coverage is the price the government paid. This cost can be obtained if it is a separately priced line item in a contract. The F-16 warranty coverage was not a separate line item in the production contract, but was a complete separate contract itself. Therefore, the explicit cost for the F-16 warranted items was easy to obtain since the items were separately priced in this contact. It is unusual to have a separate contract for a warranty. Since the F-16 RIW was to be the most complex application of a warranty to date, it was decided that having a separate contract would make the warranty cleaner and easier to administer (10). However, according to Carolyn Bowling the F-16 Contracting Officer, the difficulty was ensuring there was no overlap or conflicting terminology between the production and warranty contract provisions. Table VI provides the explicit cost of the F-16 RIW contract which were the Air Force's negotiated price for the warranties on a firm fixed price basis. These firm fixed prices for the total contract were subject to a semi-annual economic adjustment for both increases and decreases in accordance with the Bureau of Labor Statistics semi-annual labor and material indices found in sections J.22 and J.23 of the RIW contract (F33657-77-C-0062). Table VII illustrates the final price paid by the government for the F-16 RIW including the economic price, flying hour, and ECP adjust-

TABLE VI

LIMITATION ON PAYMENT OF RELIABILITY IMPROVEMENT WARRANTY COSTS
FOR EACH F-16 FLU (1:Modification 21-Atch 2)

Unit	Total Quantity	Total item Amount	Percentage of Contract Price
Flight Control Computer	442	$1,754,900	4
Head Up Display (HUD) Processor	442	$7,251,600	16
Head Up Display (HUD) Pilot	442	$7,654,200	17
Inertial Navigation Unit (INU)	442	$6,976,600	16
Radar Transmitter	442	$4,792,100	11
Radar Signal Processor	442	$2,136,900	5
Radar Computer	442	$3,146,300	7
Radar Receiver	442	$8,243,700	19
Radar Antenna	442	$2,043,700	5
Total Fixed Then Year Contract Price		$44,000,000	

TABLE VII

F-16 RELIABILITY IMPROVEMENT WARRANTY
ACTUAL CONTRACT COST (10)

Basic RIW	$44,000,000
Economic Price Adjustment	11,900,248
	$55,900,248
Flying Hour Recoupment (actual flying hours were 206,921)	(4,142,046)
	$51,758,202
ECP Changes	2,755,938
Total RIW Cost	$54,514,140

ADJUSTED COST PER FLU

Flight Control Computer	$ 2,175,466
Head Up Display (HUD) Processor	2,569,407
Head Up Display (HUD) Pilot	9,441,604
Inertia Navigation Unit (INU)	8,685,862
Radar Transmitter	5,948,655
Radar Signal Processor	2,662,607
Radar Computer	3,882,290
Radar Receiver	10,241,387
Radar Antenna	2,569,407
Total RIW Cost	$54,514,140

ments. For the two FLUs with a MTBF guarantee the supplemental fees DOD paid to elicit General Dynamics to accept the MTBF provisions in addition to those of the basic RIW, were buried in the negotiated price. Consequently, in order to determine what the additional cost for MTBF guarantees was, the official contract file would need to be consulted.

The F-16 program office never made a final adjustment for each individual FLU price. However, Carolyn Bowling, the F-16 RIW Contracting Officer, stated that as good a method as any would be to take the original negotiated FLU price (from Table VI) and divide this value by the firm fixed then year contract price (from Table VI) to arrive at each FLU's percentage of contract price. These percentages (from Table VI) could then be used to compute the final adjusted individual FLU price depicted in Table VII.

Implicit Cost. Implicit costs of a warranty are the internal costs to DOD of enforcing the warranty and documenting/complying with the claim provisions. These cost are commonly called administrative costs. One of the most important, difficult, and often confusing aspects of an RIW is its administration. The nature of the warranty, its price and particularly its duration make establishing an efficient administration procedure essential.

Data Necessary. These Administrative procedures need to insure the number of equipment failures and the reasons for the failures are well documented. By using the reading on the elapsed time indicator (ETI) at the time of

equipment installation and upon failure of the equipment, a contractor can determine the operating hours since the last failure. Therefore, it is necessary for a contractor to account for each piece of equipment by serial number and operating time.

Warranty administration requires that (DOD) maintain usage records for each item and determining if a particular piece of equipment qualifies for repair under the RIW. The technique used on the F-16 RIW was the cumulative warranty hour approach. Warranty coverage, using this procedure, is administered by maintaining usage records which compare expended cumulative flying hours of all equipment under warranty against the total number of warranted hours purchased. For example, the F-16 RIW program purchased (for the nine FLUs in the warranty program) a cumulative of 300,000 flying hours or 48 months whichever occurred first. As a unit is returned from the field for repair, the number of hours it operated is subtracted from the total of 300,000 hours purchased until the total pool is exhausted or the time limit is reached. Because some items return for repair more than others, those items receive more hours of warranty coverage and vice versa. Therefore, in effect, those items which never fail or infrequently fail transfer their warranty coverage to those that fail more often. Also, the F-16 RIW program contained a provision that if the accumulated flying hours were 250,000 or less at the end of the time period, the price of the contract would be adjusted downward at the rate

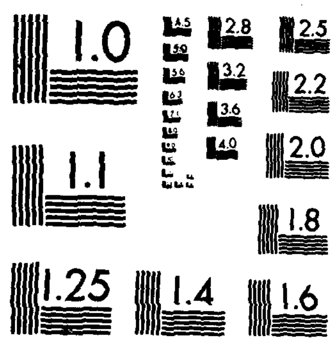
of 0.000172% of the price of the affected FLU for each hour under 250,000 (1:19). This downward adjustment was not to exceed 43% of the original warranty price of the affected FLU. The final flying hour adjustment as shown in Table VII was based on 206,921 actual flying hours.

Administrative procedures for collecting data on failures is only one implicit cost; others include, but are not limited to, contractor interface, warranty administration training, transportation, and Air Force maintenance failure-isolation costs (2:27; 46). These additional administrative costs will depend on the specific language contained in the warranty contract.

Methods of Obtaining the Data. Although the implicit costs for the F-16 RIW have already been incurred, some of these costs would be difficult to obtain. For example, one implicit cost was the transportation of the warranted item to and from the contractor's repair facility. It would be difficult to quantify these costs because there is no existing Air Force data system to collect them (36). Another example of an implicit cost incurred on the F-16 RIW was the cost of training Air Force personnel (the user DCAS, and AFPRO) in handling and administering the RIW equipment. The F-16 System Program Office contracted with Arinc Research Corporation for this training. Therefore, this cost could be obtained from the explicit price of the contract with Arinc. Because of the training program provided by Arinc, the F-16 RIW program encountered very few problems with warranty

AD-A174 588 THE FEASIBILITY OF A COST-EFFECTIVENESS ASSESSMENT OF WEAPON SYSTEM WARRA (U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST 2/2

UNCLASSIFIED J L VAN DER STELT SEP 86 F/G 14/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

claims being rejected by the contractor. Further, decals and plastic shields over the screw holes were placed on the warranted FLU boxes to help prevent unauthorized government work on the item. The only problem the F-16 RIW program did encounter was in documenting warranty claims. Sometimes when a piece of equipment was sent back to the contractor's repair facility the correct form was provided but there was inadequate documentation on why the item had been sent back (10). In other words, results of government check out tests and even explanations of why the item was taken off the aircraft were sometimes omitted. Consequently, sometimes during contractor test, the failure could not be duplicated and no problem with the equipment could be found. These were termed non-verifiable failures and are not used in mean time between failure calculations.

Not only would some implicit costs be difficult to obtain, there is currently disagreement within the Air Force as to the significance of these costs to the cost effectiveness decision of warranties. A task force team, consisting of functional specialists within the Aeronautical Systems Division (ASD) and Air Force Acquisition Logistics Center (AFALC), believe government administrative costs may generally be insignificant (2:27). Although there is no data to support this claim, they suspect that implicit costs would seldom drive the decision in a warranty cost effectiveness determination (2:27). Further, they concluded that if a model containing an extensive list of various administrative

costs could be developed the cost of developing such a model may outweigh the benefits. Finally, the team stated that further research is needed in this area.

In any case, actual implicit cost data has not been collected or analyzed to support this viewpoint. A study was to be conducted by the Directorate of Cost Analysis within ASD to develop a comprehensive estimate for the cost to the government for warranty administration. However, this effort has subsequently been cancelled, apparently due to other organizational priorities outside the Directorate of Cost Analysis (2:26; 46).

Evaluating Warranty Benefits

Based on prior discussion in chapter two and in the theoretical consideration section of this chapter, the benefits associated with a warranty must be identified and defined in order to be able to determine the cost-effectiveness of warranties. Benefits may be qualitative as well as quantitative. The theoretical model of this study addresses the benefit of increased reliability as a result of a warranty. In order to evaluate this benefit, one must determine the change in reliability and the value of this change in an operational context to DOD. On the other hand, the increased cost associated with warranties are partially offset by reductions in operational and maintenance costs.

Measuring Warranty Benefits

Keeping the definition of failure and reliability discussed in the section evaluating warranty costs in mind, one can now attempt to locate the information required to measure warranty benefits. "There is an inherent difficultly in measuring quantitative benefits of a warranty: Certain parameters of a weapon system have to be compared with what they might have been without a warranty" (6:6-6). Therefore, it is hard to avoid some conjecture in this situation. A warranty extends a contractor's responsibility to operational or field performance for the period of the warranty coverage. Consequently, a warranty can provide increased assurance that operational performance will be as specified. For example, on the F-16 RIW, this assurance was quantified through the use of the reliability parameter of MTBF. Increased reliability means fewer failures. "The number of failures influences sparing levels, maintenance manpower levels, material costs for repair, and other logistics /support elements associated with failures." Accordingly, warranty benefits such as these "can be translated into statistical measures of benefits and associated costs that can be used in the conduct of a" cost-effectiveness assessment of warranties" (6:7-12). In order to accomplish this, DOD needs to measure the change in reliability due to the warranty and the value of that change in an operational context. To measure what the reliability of the F-16 equipment would have been without a warranty requires judgments of a conjectural nature. The Air Force

Acquisition Logistics Division (now called the Air Force Acquisition Logistics Center) and the F-16 System Program Office jointly undertook a study to project the expected mean time between removal (MTBR) for each FLU without a warranty. This study is not readily available from the F-16 program office or AFALC which makes it difficult to evaluate the rationale used to project these expected MTBRs without a warranty. Table VIII presents the comparative information on expected MTBR without a warranty and achieved MTBR with the warranty for the nine F-16 RIW FLUs. The achieved MTBR for all but one of the FLUs (radar antenna) are equal to or greater than their expected values. While these expected values could be used to measure the change in reliability due to the warranty, a better method would be to "compare the reliability attributes of the F-16's warranted equipment to the functionally similar attributes of non-warranted equipment in the F-15" (14:1-5). This is the procedure Arinc Research Corporation used for their interim evaluation of the F-16 RIW program. In a 1985 AFIT thesis, Captains Steven Lemke also used the same methodology as Arinc Corporation; the difference being he was able to use the final F-16 RIW program flying hour and failure figures from the Air Force Maintenance Data Collection System (35). Although the evidence was not overwhelming, Lemke's research stated there was evidence to "indicate the reliability of the warranted F-16 FLUs was greater than the reliability of functionally similar non-warranted F-15 LRUs" (35:69). On the other hand, Arinc's

TABLE VIII

EXPECTED AND ACHIEVED MEAN TIME BETWEEN REPAIR VALUES FOR F-16 RIW FLUs (14:2-8; 35:54,60)

Nomenclature	Mean Time Between Removal (MTBR)(Flight Hours) Expected	Achieved
Flight Control Computer	100	362
Head Up Display (HUD) Processor	210	652
Head Up Display (HUD) Pilot	140	370
Inertia Navigation Unit (INU)	160	160
Radar Transmitter	110	275
Radar Signal Processor	120	484
Radar Computer	240	372
Radar Receiver	130	187
Radar Antenna	550	183

Note 1: Expected MTBR figures are based on a joint F-16 System Program Office and Air Force Acquisition Logistics Division (now Air Force Acquisition Logistics Center) study as reported in Arinc Research Corporation interim evaluation of the F-16 RIW program.

Note 2: Achieved MTBR figures are based on the flight hour and failure data in Appendix A of Captain Steven Lemke's AFIT thesis, a Comparative Evaluation of the Reliability in Line Replaceable Units Warranted Under the F-16 RIW. MTBR was calculated by dividing the total flight hours for the warranty period (220,425) by the number of failures for each FLU over the four year warranty period.

evaluation before the warranty period was over concluded that "the data cannot be said to favor the case for the F-16 RIW program having provided significantly higher reliability than would have occurred without the RIW program" (14:2-12). Also, both "F-16 LRU's that were procured under a MTBF guarantee exhibited significantly better reliability than their F-15 counterparts" (14:2-12). However, neither research effort attempted to evaluate the costs and benefits of the F-16 RIW.

While either of these methods could provide the required statistics to measure the benefit of the change in reliability due to the warranty, neither address the value of that change to DOD in an operational context. Further, unless DOD can compare the change in DOD costs to the change in benefits as a result of increased reliability, a meaningful cost-benefit or effectiveness analysis seems unlikely. The historical data required for comparison of the manufacturing cost of increased reliability with that of the benefit (value to DOD) of the increased reliability seems to be lacking.

In summary, changes to DOD's cost resulting from a warranty are attributed to the price of a warranty plus the DOD cost of enforcing the warranty coverage minus any reduction in operation and maintenance (O&M) costs resulting from the improved reliability. A warranty price is a function of the total cost to the contractor (manufacturing cost of building increased reliability into a product and warranty claim cost expenses) and the level of profit as determined by contractor versus DOD negotiating ability. The

costs of enforcing warranty coverage are DOD's administrative (implicit) expenses incurred. Finally, the cost savings of reduced O&M costs is the direct result of any increased reliability during the warranty coverage.

In this chapter the feasibility of obtaining the theoretical information identified in chapter two to assess the costs and benefits of weapon system warranties was discussed. Data gathered on the F-16 RIW was used as the example of the type of information currently available to measure warranty costs and benefits. The problems with measuring warranty costs and benefits along with the problems found in obtaining this data was also discussed. The next chapter provides the conclusions and recommendations for future research necessary to effectively evaluate weapon system warranties.

V. Conclusions and Recommendations

In accordance with Public Laws 98-212 and 98-525, the DOD is required to conduct cost/benefit studies of warranties. This thesis considered the information required to do such an analysis and investigated the availability of such information by looking at the F-16 RIW contract as an example.

Conclusions

The analysis of the conclusions from chapter four can be separated into the categories of costs and benefits.

With Regard to Costs. These costs include both the explicit and implicit expenses of warranty coverage to DOD.

Explicit Cost. The explicit price of a warranty is known if it is itemized such as it was for the F-16 RIW; however, the price is not always broken out this way. The F-16 RIW was an unusual case in that the warranty coverage was a separate contract from the production contract. Consequently, DOD's explicit cost for each warranted item was separately priced in this contract. Generally, a common practice in DOD is to have warranties as either a separate line item or as a percentage of direct cost of the production contract. The direct (explicit) cost of a warranty is the price paid by DOD which is a function of the manufacturer's total cost and DOD's negotiating power. Although the price paid for a warranty may be known, typically DOD does not know

the level of profit a contractor is making because manufacturer's total cost of providing the warranty is unknown.

Manufacturer's Total Cost. It is important for DOD to have historical data on a manufacturer's total cost of a warranty in order to better negotiate the price of the warranty with the contractor. A manufacturer's total cost is a function of warranty claim costs and the manufacturing cost of building increased reliability. As indicated in the assessment in chapter four, these costs are not readily available in Air Force records.

Warranty Claim Costs. Warranty claim costs consist of the manufacturer's cost of a failure times the number of failures. With regard to estimating a manufacturer's cost of a failure, there were two problems encountered in this research. The first was the difficulty in measuring a manufacturer's cost of a failure unless data is provided by the contractor. This information can be obtained, prior to the warranty, in a contractor's proposal and after a warranty expires in the contractor generated warranty data reports as long as the information was a requirement of the contract provisions. These costs are important to the Air Force in that they provide information to be used for comparing a contractor's cost with similar systems, supporting the price of the warranty, and also for evaluating the warranty after it expires. For the F-16 RIW contract, one can not determine the actual cost of repairs because not all the warranty data reports are available. Even if these reports were all

available, there are some doubts about the data provided - for instance, very low repair parts cost and the fact that labor hours but not labor cost reported. The second problem, of estimating the contractor's warranty repair cost based upon Air Force repair of similar failures suffers from difficulties in that the Air Force Maintenance Data System (MDCS) does not always identify failures in a comparable manner to that of warranty contracts nor do the costs collected correspond to equivalent contractor areas of responsibility. A further problem is that in some instances, due to procurement of state-of-the-art technology, there is no Air Force experience in repairing equivalent systems.

Manufacturing Costs. Warranty manufacturing costs are the cost of building reliability into a product. The problem in this area is that although historical equipment manufacturing cost data is available it does not provide insight into the cost of building increased reliability into an item. This is the most significant barrier to research in the area of evaluating the costs and benefits of warranties. The costs of warranty induced improvements are an intrinsic part of contractor manufacturing costs; this data is usually proprietary and not obtainable outside the firm. Even if the data were made available, it would take an extensive knowledge of the technology involved and the contractor's cost accounting system. An Aeronautical Systems Division contract price analyst stated that the time and

effort necessary to gather and put the data into a usable format could outweigh any benefits (44).

Implicit Cost. An important area of implicit costs relates to the internal costs of enforcing a warranty. A basic difficulty in this regard relates to the problem of defining a failure and proving that a failure has occurred. For example, the Air Force Maintenance Data Collection System calculates mean time between repair (failure) using only actual flying hours. Contractually, the reliability of equipment is usually measured by a mean time between failure which includes total operation - both ground and flight times. Therefore, defining a failure is a crucial determinant of a contractor's required performance. When the DOD and contractor discuss the term "failure", it can take on a number of different meanings. Failure could mean a complete or partial breakdown in operation of an item. For partial breakdowns the item may still be operational but not at 100 percent capacity. With regard to DOD's point of view, any breakdown of an item should be repaired or replaced by the contractor. Conversely, from the manufacturer's point of view, any "failure" costs money and decreases profit. Unless the term "failure" is explicitly defined in the contract, the DOD could have problems in documenting and enforcing warranty claims.

With regard to the costs of enforcing DOD warranty claims, not much is known. Although, standard rates have been suggested for the administrative cost of enforcing Aeronau-

tical Systems Division warranties, actual cost data have not been collected and analyzed. A difficulty is that there is currently no Air Force data system available to track these costs. Consequently until these costs are collected and analyzed the significance or insignificance of implicit costs can not be substantiated.

Apart from the costs of enforcing warranties, a positive effect of warranties results from the reduction in operation and support costs from having more reliable equipment available and from contractor repair. Although life cycle cost models have occasionally been used to estimate these savings, nothing has been done to empirically validate such estimates.

With Regard to Benefits. The benefits to DOD are the value of increased reliability in an operational context as a result of a warranty. Any increase in reliability means fewer failures and fewer failures mean an increase in availability. Consequently, increased reliability has a impact on system availability. The most significant problem of measuring the change in reliability due to a warranty is the difficulty in separating the benefit attributable to other factors. Other contractual techniques, such as award fees, ECPs, and increased quality control inspections affect the change in reliability too. Unless the overlap between these contractual techniques can be identified, defined, and measured there will be significant complications in performing cost-benefit and warranty effectiveness analysis. Carolyn

Bowling, Contracting Officer on the F-16 RIW believes that it will be difficult if not impossible to separate the effect these different contractual techniques have on equipment reliability (10).

Recommendations

System level warranties involve many issues. The scope of this research effort did not permit an investigation of them all. However, in the course of this effort several areas for future research were apparent. These areas include the following.

First, because warranties on major weapon systems are now required by law unless they are determined not to be cost-effective, a method of establishing an integrated and centralized warranty data base would be beneficial for future warranty evaluation. Specifically, a data base that collects information on a manufacturer's cost of building reliability into a product would be helpful to DOD in warranty negotiations.

Second, a detailed analysis of the relevant DOD implicit costs needs to be conducted. This analysis should identify and evaluate the different cost categories that contribute to DOD's cost of enforcing warranty coverage. Once completed, the analysis could validate whether government administrative costs are important in the determination of the effectiveness of warranties.

Third, the feasibility of separating the effects of a warranty and other contractual provisions on increased weapon

system reliability should be studied. Some of these other contractual provisions are Engineering Change Proposals (ECPs), award fees, and increased quality control programs.

Finally, a study of the effect warranties could have on DOD organic maintenance capability in wartime should be done. The concern here is that warranties could cause the DOD to rely on the peacetime situation where defective products are sent back to the contractor for repair. What effect will warranties have on readiness in wartime situations?

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As DOD's percentage of the budget continues to decline, there is an increasing need to get more for the defense dollar. Weapon system warranties which are now required by law are one way to achieve this objective. Congress has requested that only cost-effective warranties be procured. Consequently, DOD is requiring all services to conduct cost/benefit studies of warranties.

This thesis considered the information required to conduct such an analysis and investigated the availability of such information by looking at the F-16 Reliability Improvement Warranty contract (F33657-77-C-0062) as an example. A simple theoretical manufacturer's cost model of warranty relationships is used as a reference in identifying the overall structure and general types of information necessary for warranty cost/benefit analysis. Warranty experts from Aeronautical Systems Division (AFSC) were interviewed and asked about the availability of the information discussed by the model. The research concluded that critical information nescessary to perform valid cost/benefit or effectiveness assessments of warranties is missing.

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